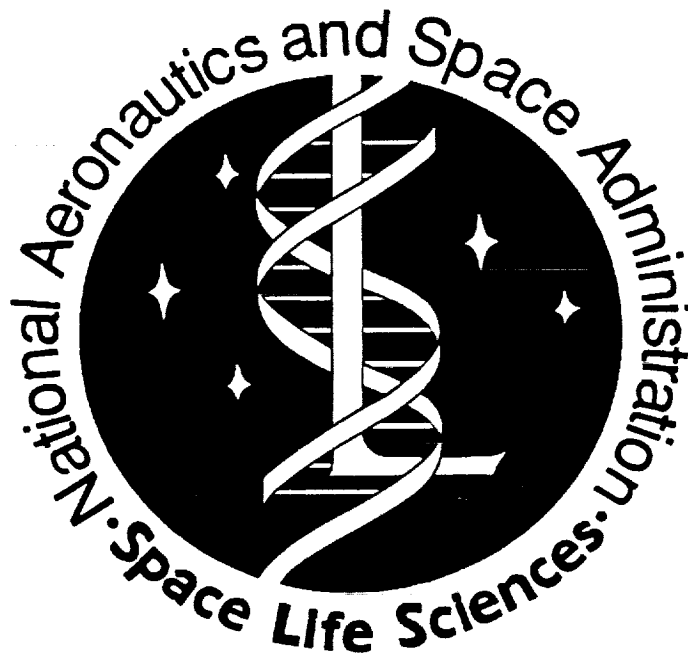


SPACE LIFE SCIENCES STRATEGIC PLAN

1991



Life Sciences Division
Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, D.C.

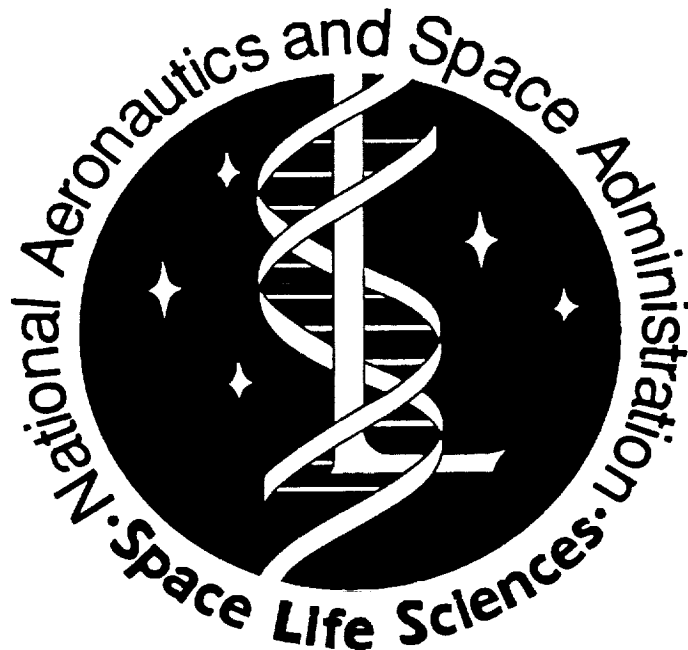
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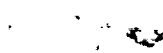
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Washington, D.C.



THE
OFFICE OF THE
ATTORNEY GENERAL
STATE OF NEW YORK
IN SENATE
JANUARY 10, 1911
REPORT
ON THE
ADMINISTRATION OF THE
OFFICE DURING THE
YEAR 1910
BY
JAMES C. HARRIS
ATTORNEY GENERAL

FOREWORD

In April 1989, the initial version of the Life Sciences Division Strategic Implementation Plan was published. That document described the Life Sciences Division's programs and placed them in scientific and programmatic perspective. It addressed planned activities, proposed program initiatives, and anticipated future enhancements in order to develop a logical direction for NASA's life sciences program.

The focus for the National Space Policy was highlighted by President Bush's speech of July 20, 1989, in which the President set out a clear long-term goal for the U.S. space program, beginning with the building of Space Station Freedom, then returning to the Moon to stay, and proceeding with the human exploration of Mars. NASA's subsequent planning in support of the President's initiative has identified specific biomedical and life support research activities and their schedules that must be carried out to realize these exploration commitments. In December 1990 the Advisory Committee on the Future of the U.S. Space Program published its report. The programmatic recommendations contained in their report were factored into the 1991 Strategic Plan.

The 1989 and 1990 issues of the Life Sciences Division Strategic Implementation Plan established a baseline for the present planning process. The latest issue of the Space Life Sciences Strategic Plan has been updated and expanded to address the prevailing budgetary and programmatic realities. It incorporates the extensive analysis of the exploration program needs and planning for ongoing research and related activities not directed toward exploration initiatives. The current plan reflects recent developments within the context of programmatic, budgetary and organizational decisions made since 1990. The resulting maturation of programmatic planning formed the foundation for the President's FY 1992 budget request and is reflected in the current strategic plan.

Arnauld E. Nicogossian
Director, Life Sciences Division

SPACE LIFE SCIENCES STRATEGIC PLAN — 1991

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I. INTRODUCTION

Over the last three decades the life sciences program has significantly contributed to NASA's manned and unmanned exploration of space, while acquiring new knowledge in the fields of space biology and medicine. The national and international events which have led to the development and revision of NASA strategy will significantly affect the future of life sciences programs both in scope and pace. This document serves as the basis for synthesizing the options to be pursued during the next decade, based on the decisions, evolution, and guiding principles of the National Space Policy.

A. NATIONAL SPACE POLICY

The Presidential Directive on National Space Policy, approved by President Reagan on January 5, 1988, and reaffirmed by President Bush on November 2, 1989, states that "a fundamental objective guiding United States space activities has been, and continues to be, space leadership." Select goals of the United States Civilian Space Program, as they relate to the life sciences programs, are:

- To obtain scientific, technological, and economic benefits for the general population
- To improve the quality of life on Earth through space-related activities
- To expand human presence and activity beyond Earth orbit into the solar system
- To promote international cooperative activities.

These goals were highlighted again in President Bush's speech on July 20, 1989, which emphasized major new commitments to space exploration, including a return to the Moon and the exploration of Mars. The President stressed that leadership in space can only be maintained through the active development of a vital scientific and technology research base. These guiding policies provide the basis for the program in the space life sciences. Two major overarching initiatives implementing the President's commitments have been put forth:

- Mission from Planet Earth, to initiate the exploration of the Moon and Mars.
- Mission to Planet Earth, to provide a clearer understanding of global climate change and the impact of human activities on Earth's biosphere.

Each of these overarching initiatives can potentially impact the life sciences programs. Thus it is imperative to examine the extent that life sciences programs will be involved in these initiatives and to establish a set of associated strategic ground rules for a core program and the initiatives.

In December 1990 the Advisory Committee on the Future of the U.S. Space Program made recommendations to the NASA Administrator on the overall strategies to be used in implementing the U.S. space program for the coming decades. These recommendations were transmitted by the NASA Administrator and the Committee Chairman to the Vice President of the United States, who chairs the National Space Council. Their report stresses, among other recommendations, that:

- "...science gives vision, imagination, and direction to the space program, and as such should be vigorously protected..."
- "...fundamental uncertainties remain with respect to the feasibility of long-duration human space flight, uncertainties that revolve around the effects of solar flares, muscle deterioration due to weightlessness, the loss of calcium in human bone structure, and the impact of galactic cosmic radiation. These basic issues need to be resolved before undertaking vast projects entailing long-duration operations involving humans in space. We thus arrive at what we believe is the fundamental reason for building a space station: to gain the much needed life sciences information and experience in long-duration space operations. Such information is vital if America is not to abdicate its role in manned space flight."

The Committee also underscored the need for investments in the technology base, specifically calling for "...long-duration closed ecosystems and life support systems...and artificial gravity..."

Overall, these recommendations are consistent with the traditional goals and objectives being pursued by NASA, the Office of Space Science and Applications (OSSA), and the space life sciences program. Over the past 5 years the relevance of the life sciences program priorities and their compatibility with the long-term NASA goals were examined by internal (NASA Advisory Council) and external (National Academy of Sciences) advisory committees. Their findings were reaffirmed by the Advisory Committee on the Future of the U.S. Space Program.

B. SPACE LIFE SCIENCES DIVISION OVERVIEW

The Life Sciences Division is one of eight divisions of the Office of Space Science and Applications of the National Aeronautics and Space Administration. The Division is responsible for planning, directing, implementing, and evaluating that part of the overall NASA program which deals with the understanding of how living systems respond to the space environment; the search for the origin, evolution, and distribution of life in the universe; the development of the scientific and technological foundations for expanding human presence beyond Earth orbit and into the solar system; and the provision of operational medical support to all space missions involving humans.

The space life sciences program fosters research in the study of life and its processes under the influence of different environmental conditions, exhibited by both planetary surfaces and weightlessness. In order to fulfill this mission the characteristics of life-sustaining environments should be understood first, and then, by careful examination of individual parameters such as radiation, gravitational forces, and barometric pressure, the reaction(s) of living organisms to environments encountered in the universe should be determined. Ultimately, by studying such processes, we will be able to document underlying critical physiological mechanisms and develop predictive models that can provide new insights about the responses of living systems to environmental challenges. A benefit from such knowledge is the design of strategies for protecting living systems, such as countermeasures enabling humans to cope with the effects of weightlessness and safely return to Earth. Another benefit will be the development of life support systems and specific technological requirements for sustaining life in unusual and hostile environments. In the case of human space flight, the knowledge gained is transferred to the physicians and engineers for incorporation into operational systems. In the case of robotic exploration of the solar system, the information is a direct input into the requirements for the implementation of planetary protection activities.

The life sciences program maintains a close working relationship with the Office of Space Flight on operational issues dealing with crew health, and with the Office of Aeronautics, Exploration and Technology in the establishment of requirements and in-space technology developments. These goals are pursued through an integrated set of activities in ground- and space-based research laboratories. The space-based laboratories currently consist of the U.S. Space Shuttle and Spacelabs, and the Soviet Space Station (Mir) and unmanned biosatellites (Cosmos). In the near future, the program will utilize the Space Station Freedom; Lifesat, a reusable biological satellite; planetary probes and spacecraft; and Earth-orbiting platforms. The program is accomplished with the participation of NASA field centers, other Government agencies and organizations, universities, and United States industry. Significant reliance is placed upon international participation and contributions by other spacefaring nations through established cooperative agreements.

The Life Sciences Division supports clinical, applied, and basic research. The research is conducted both in ground-based, airborne, and space flight settings. The administration of the programs and projects is achieved through four closely integrated organizational elements represented in Figure 1. A more complete description of specific strategies is presented in Appendix I.

In addition to the implementing structure noted above, there are three focused activities that cut across several disciplinary areas. These activities are extremely important in fulfilling our objectives.

The ***Life Sciences Educational and Training Program*** is an important element in developing a future cadre of expertise. The key components of the educational program are target schools and graduate curricula.

NASA Specialized Centers of Research and Training (NSCORT), a university/industry/government-based program, initiated in FY 1990 and focused on specific areas of interest to space life sciences. This provides for a stable multi-year funded research activity which contributes to the training of a new generation of space life scientists.

Figure 1 Life Sciences Division Programs/Projects

AEROSPACE MEDICINE

- Operational medicine support
 - Clinical medicine
 - Medical standards
 - Longitudinal studies
- Identification of requirements for biomedical and life support research

LIFE SUPPORT

- Applied biomedical and life support research, including:
 - Space physiology and countermeasures
 - Radiation health
 - Environmental health
 - Space human factors
 - Controlled ecological life support systems

RESEARCH PROGRAMS

- Basic science research, including:
 - Space biology
 - Biospheric
 - Exobiology
 - Planetary protection

PROGRAMS AND FLIGHT MISSIONS

- Implementation of flight projects;
 - Aircraft
 - Space Shuttle/Spacelabs
 - Free flyers
 - Space Station Freedom
 - International missions
- Advanced technology development and mission planning
- Instruments for planetary spacecraft

Life Sciences Research Groups (LSRGs) are being established around unique national facilities at NASA field centers. Composed of teams of scientists and engineers, they will function in a program/project mode with multi-year Research and Development activities and stable support. LSRGs utilize expertise from within NASA and from the broader life sciences community at large.

C. SPACE LIFE SCIENCES GOALS AND OBJECTIVES

The manned space program has demonstrated that Earth-bound life can be sustained beyond the confines of our planet. Unmanned planetary probes have raised many unanswered questions about the origins of life, its distribution, and the factors that have influenced its development. Through the space program the universe has become an accessible domain, opening unprecedented possibilities for probing life processes.

So far the research conducted in space has been mostly applied. This was primarily dictated by the nature and type of missions flown. While biological sciences research has been conducted mostly under simulated conditions in Earth-based laboratories, the Spacelab life sciences missions will open a new window of opportunity for the biomedical sciences, which will fully mature in the Space Station Freedom era. Basic research is necessary to define mechanisms which are involved in the physiological changes observed in space flight and also to expand our understanding of life processes. While there is a significant overlap between the basic and applied research, it is the basic research that holds the promise for acquiring knowledge which can benefit the general population back on Earth.

The major life sciences goals are:

- Ensuring the health, safety, and productivity of humans in space.
- Acquiring fundamental scientific knowledge concerning space biological sciences.

These goals in turn are supported by the following objectives:

1. To provide for the health and productivity of humans in space,
2. To develop an understanding of the role of gravity on living systems,
3. To expand our understanding of life in the universe, and
4. To promote the application of life sciences research to improve the quality of life on Earth.

The relationship of the goals and objectives to the life sciences programs is discussed below.

1. To provide for the health and productivity of humans in space

Historically, exploration of new and hostile environments was made possible through the establishment of an adequate knowledge base of the physiological responses to the prevailing living conditions and development of functional protective procedures and systems. Since humans have left the confines of Earth, it is imperative to learn how they adapt to and perform in space, and to understand the biomedical time course and health implications of space travel so that efficient life support systems are developed, regardless of the duration of space missions.

Within the Life Sciences Division, the operational medicine program is responsible for the health maintenance and care of astronauts. Some of the most important operational activities include the development of procedures to assure crew health in flight and during landing and egress of the extended Shuttle Orbiter missions; development of health maintenance facilities (HMF) tailored to specific needs of different mission lengths and scenarios; definition of medical requirements for an Assured Crew Return Vehicle (ACRV); refinement of medical selection and retention standards; and establishment of medical training programs for flight crews. The primary goals of this program are to identify and anticipate potential health problems, develop preventive and therapeutic procedures, and establish research priorities to address identified biomedical challenges.

Today we know four biomedical challenges that potentially limit the duration of human space flight: physiological deconditioning, health effects of exposure to space radiation, psychosociological effects of isolated, confined and hostile environments involving complex operations through interface with space systems, and the need to meet critical life support requirements on lengthy space journeys. The research programs designed to address and mitigate these challenges are addressed below.

Space Physiology and Countermeasures concentrates on physiological decrements resulting from space flight, which become a greater concern as the duration of the space mission is extended. Ground and space research have identified unresolved scientific issues relevant to the following areas: cardiopulmonary deconditioning; neurophysiology and performance degradations, particularly space motion sickness; eliciting impacts of exposure to long-duration spaceflight on the immune system and the potential for illness; physiological and emotional stress and its influence on pharmacologic consequences; and bone, endocrine, and muscle systems changes.

Radiation poses health risks for long-duration missions in low Earth orbit and beyond, and in particular during long stays on the Moon or the 1 to 3 years required for a round trip to Mars. While considerable information is available about the physical nature of space radiation, substantive questions remain concerning the carcinogenic and other biological effects of exposure to galactic cosmic radiation and solar particle events. More information is needed on the shielding required to protect flight crews, early warning systems, and instruments to reliably measure radiation doses.

The success of extended missions will largely depend on the **psychosociological aspects and interactions** among the space crew and between the space and ground personnel. Little information is available on interactions and productivity among small, isolated groups living in weightlessness or on planetary surfaces with a fraction of Earth's gravity level for lengthy periods of time. The most pressing issues for extended human missions, which will offer only limited possibilities for emergency rescue and return to Earth, involve interpersonal interactions, human/machine interface, crew selection, command and control structure, and crew motivation.

Environmental factors and life support requirements directly relate to both the physiological and psychological well-being of space crews. The primary concerns in this area include the establishment of requirements for a regenerative food, air, and water system; development of an environmental monitoring system capable of detecting sources and types of contamination; validation of procedures for decontamination; design of the most effective systems to support EVA operations; and analysis of optimal habitability conditions for extended missions. The development of a regenerative life support system is especially challenging. The Controlled Ecological Life Support System (CELSS) program focuses on combining biological and physiochemical processes to provide food, air, and water by recycling and removing waste materials inside the spacecraft. The behavior and productivity of plants in space, however, is not well understood, and needs to be vigorously pursued.

2. To develop an understanding of the role of gravity on living systems

Gravitational Biology uses real and simulated weightlessness as an experimental tool to understand biological organization and function, and the role that gravity plays in the evolution and development of living systems. It addresses fundamental questions concerning how living organisms perceive gravity, how gravity is involved in determining developmental and physiological status, and how gravity has affected evolutionary history. While these questions are motivated primarily by scientific interest, such basic knowledge is critical to determining if life can function effectively for extended periods in weightlessness or reduced gravity, as on the Moon or Mars, or if an artificially induced gravitational force is required. Space-based research, which requires variable-force centrifuge facilities, provides unparalleled opportunities to expose organisms to fractional gravity levels ranging from 0 to 1 g over several generations with large sample sizes; this approach allows us to investigate the effects of gravity on living organisms in a controlled fashion.

3. To expand our understanding of life in the universe, including the interaction of biological and planetary processes on Earth

Exobiology focuses on questions long pondered by humankind, such as: Are we alone in the universe? What led to the origin of life on Earth? Data suggest that the early environments of Mars and Earth were similar and that samples from Mars could fill gaps in Earth's geological record, in particular for the time before 3.5 billion years ago. Any valid indication of life on Mars, extant or extinct, would support the hypothesis that life can originate wherever the physical and chemical environment is favorable. For these reasons, robotic probes followed by human missions to Mars will yield important scientific answers critical to exobiology.

The **Biospheric Research Program** focuses on biogeochemical cycles and on biogenic gases as components of those cycles; studies population dynamics as the underlying mechanism of biological interactions; and constructs and validates predictive models of biospheric behavior and applies this knowledge to the study of human health. The program uses ground-based techniques to study individual sites, and extends those observations to global scale by use of aircraft and space-based remote sensing in a multidisciplinary fashion. In the near term, the program is involved in the study of globally important tropical and temperate forests and wetlands ecosystems.

4. To promote the application of life sciences research to improve the quality of life on Earth

The research conducted by the space life sciences program has resulted in an expansive number of "spinoffs." First, by studying responses of living systems to microgravity we are beginning to understand the role gravity plays in health and disease processes. Such is the case in orthostatic intolerance, osteoporosis, muscle atrophy, and the need for and type of exercise to prevent such events. Second, by developing non-invasive physiological monitoring instrumentation and means for transmission of biomedical data from space, we have designed systems which are now routinely used by the medical profession for health care delivery. Such is the case for implantable and programmable pacemakers, defibrillators, medication dispensing systems, intensive care monitoring procedures, and telemedicine concepts. Through the study of biospherics, specifically populations and their habitats, we are evaluating the feasibility of global monitoring of vector-borne diseases (e.g., malaria). By designing regenerative life support systems capable of producing food, air, and water we anticipate significant contributions to agriculture in general. It is our belief that as we continue research and technology developments for more ambitious missions with humans, many other benefits will become available to mankind.

D. SPACE LIFE SCIENCES PRINCIPLES

The space life sciences program is dependent upon operational experience and continuity of scientific inquiry. The scientific base is essential in planning future missions on a schedule compatible with NASA long-range options. Significant emphasis and reliance is placed upon the interactions of NASA and the scientific community in devising strategies and maintaining excellence through the peer review process outlined in the Division's "Science Management Plan."

Five underlying principles are used for the implementation of a balanced and viable life sciences program:

1. Maintain and expand the unique space research facilities located at NASA's field centers, universities, and within the private sector;
2. Maintain timely and sustained access to space to conduct critical experiments;
3. Coordinate research programs with national and international organizations;
4. Develop and maintain a unique national database for space life sciences;
5. Develop and sustain an expanding training program in space life sciences.

The strategies for program implementation described in Section III have evolved within the context of the National Space Policy, NASA long-range planning, the OSA Strategic Plan, and recommendations of life sciences advisory groups.

E. SPACE LIFE SCIENCES VISION

The second half of the 20th century has seen unprecedented breakthroughs in the fields of biology and medicine. In a relatively short period of time in the history of mankind, scientists have begun to probe the life process at the most basic level, the cell. Almost overnight an explosion in knowledge of health and disease, genetic engineering, evolution of life on Earth, and environmental biology has occurred. Despite these biomedical advances, the field of space biology and medicine still remains in its infancy. Though significant progress has been made in ground-based research, validation of these findings by actual space flight data remains problematic because of the requirements for flight opportunities.

As we approach the 21st century, we anticipate more frequent access to space for life sciences and thus will gather the much needed information in space biology and medicine. The legacy of the Apollo, Skylab and Viking Programs has firmly established the biological and medical foundations of the space life sciences current knowledge, and raised many unanswered questions. It is our vision that 1991 will herald the revitalization of the space life sciences program, beginning with the flight of the first dedicated life sciences Spacelab mission, originally planned for 1984.

During the next 10 years we will have begun to understand the effect of long-duration space flight on humans, our most precious resource. Through extended-duration Spacelabs, Space Station Freedom missions, and the LifeSat reusable biosatellite, we will carry out an evolutionary program to study the responses of biological systems to reduced gravity and space radiation. We will make significant advances in understanding and quantifying the health hazards from both solar flares and galactic cosmic radiation. Studies of radiation shielding and countermeasures to physiological deconditioning will be underway to enable humans to safely venture beyond the confines of low Earth orbit and into the solar system.

During the first decade of the 21st century we will have determined and validated measures to provide medical care and preventive health maintenance, and will accurately predict the health risks for long-term sojourns in space and on the surfaces of the Moon and Mars. The provision of closed loop life support systems based on integrated biological, physical, and chemical processes, including utilization of *in-situ* planetary resources, will assure the capability for more ambitious exploration missions.

Gravity's role in a wide variety of fundamental biological processes in plants and animals will be understood through our ability to probe mechanisms of biological perception of gravitational forces and determine the responses of living systems to the space environment, from single cells to complex multicellular organisms, to mixed populations of organisms. The systematic exploration of a wide range of gravity levels, available only through the use of a suitable on-orbit centrifuge facility, Spacelab missions and Space Station Freedom, will help us understand the need for artificial gravity during long-term space travel.

Our knowledge of the relationship of life to natural processes occurring in the universe will have been expanded, and a direct search for signs of life elsewhere will have been conducted. A sophisticated microwave observing project will have completed a comprehensive search for radio signals stemming from extraterrestrial technologies within a defined search space, thereby extending our knowledge of life in the universe.

By the end of this century, we will have made great strides in establishing a space- and ground-based monitoring and research network to improve our understanding of the factors determining the health of the Earth's natural global processes, including the quantification and trends of human impact upon those processes. Specifically in the life sciences, we will have developed and implemented the capability to predict the location, timing, and potential severity of malaria outbreaks, thereby aiding overburdened national and international health agencies around the world. Extrapolation of this capability to other diseases and ecological conditions will be underway. A major increase in our understanding of the population and community dynamics in natural ecosystems will have occurred, and ecologists working at those scales will be ready to make optimum use of the Earth Observing System (Eos) and Earth Probes data that has become available as part of Mission to Planet Earth. In addition, an interagency program will be underway to acquire a predictive understanding of freshwater ecosystems and how to improve the management of these valuable resources.

Technologies developed initially for space, such as telemetry, automated fluid handling, electronics, image enhancement, and miniaturization, will have enriched conventional medical capabilities. Devices for preventive screening and monitoring, computer-aided diagnosis, diagnostic imaging tools, implantable systems, telemedicine, and research tools opening new windows into human health will continue to be the subject of productive research.

The accomplishments of the space life sciences program will have direct relevance to the exploration missions, while addressing very important scientific questions with profound societal implications on the origin of life, its fate, and the probability of its existence somewhere else in the universe. The space life sciences program will continue to attract outstanding scientists. The recent addition of the NASA Specialized Centers of Research and Training (NSCORT) and Life Sciences Research Groups (LSRG) programs will continue to expand both the interest and contributions of the scientific community.

We expect that by the turn of this century the establishment of a national and international space life sciences entity will be a reality, benefiting not only space exploration but also continuing to stimulate scientific discovery and provide benefits to the health and well-being of all mankind.

II. THE SPACE LIFE SCIENCES STRATEGY

A. PROGRAM PRIORITIES

The life sciences program strategy is guided by two major goals:

Goal I — Ensuring the health, safety, and productivity of humans in space

Goal II — Acquiring fundamental scientific knowledge in space life sciences.

The two goals are interactive and require continuous and careful balance. The first is mandatory in the support of overall national human space flight goals, while the second is both supportive of the first and an inherent part of NASA's space science and technology strategy. The sequence, pace, and schedules for implementation of the space life sciences program strategy are based upon the overall goals of the National Space Policy. Since 1989 the following priority order has been established to implement the space life sciences strategy:

1. Maintaining the existing flight and ground research and development programs, and expanding their scope as appropriate to support future needs by the following actions:
 - enhancing support to the NASA centers' unique facilities and talents;
 - establishing NASA Specialized Centers of Research and Training at universities;
 - enhancing access to space through development of new opportunities for small missions.
2. Developing and implementing an appropriate in-space infrastructure evolving through Spacelabs, LifeSat and Space Station Freedom, and conducting critical research for advanced missions with humans;
3. Coordinating space exploration activities with other federal agencies and international partners;
4. Applying knowledge and technology gained from space exploration to the solution of problems on Earth.

The program strategy to provide the medical and life support knowledge and scientific rationale, as outlined in the Report of the Advisory Committee on the Future of the U.S. Space Program, is described in the following sections.

B. THE CORE PROGRAM STRATEGY

The core space life sciences program comprises on-going programs, enhancements to the research base, small missions, moderate missions, and Space Station Freedom utilization and support. This program, while contributing to the preparation for human missions to the Moon or Mars, would be needed even in the absence of such an overarching initiative in order to further the goals of NASA and space life sciences.

The strategy for the acquisition of fundamental scientific knowledge in space life sciences must meet two challenges. First it must be responsive to the priorities of the communities it serves. The space life sciences program must be responsive to two primary communities — the scientific community and mission implementors. The latter group seeks applied knowledge in specific disciplines to enable the development and implementation of missions with optimal medical and life support systems. The scientific community seeks to utilize space flight opportunities to obtain basic and applied scientific knowledge. Because of the nature of these needs, a degree of commonality exists in the research priorities that have been established by both communities.

The second challenge is to match science with the most appropriate platform. A significant portion of the life sciences research can be conducted in ground-based laboratories. However, this research, in order to be effective, requires that ultimate validation of hypotheses and ground-based experimental models be conducted under space flight conditions. When flight experiments require humans as either the most appropriate test subjects or as the experimentors, then the manned mission is the necessary platform. When scientific objectives can be achieved without direct human intervention, then an unmanned spacecraft is the preferred platform. When the most appropriate setting is a ground-based laboratory, the strategy focuses upon the use of university and/or industry facilities, unless NASA-unique capabilities are required.

The elements of the space life sciences core program strategy are shown in Figure 2 and described in the following section.

1. Ongoing programs

The **Operational Medicine Program** supports the planning and execution of manned missions, and the development of advanced medical care systems, involving hardware for diagnosis and treatment; medical protocols and procedures for zero-gravity; and the requisite knowledge of zero-gravity physiological changes and associated risks required to practice medicine in space. This understanding is essential in order to implement an effective countermeasures program for missions varying in length up to 6 months.

Research and Analysis programs include: Space Physiology and Countermeasures; Space Human Factors; Environmental Health; Radiation Health; Controlled Ecological Life Support Systems; Space Biology; Biospheric Research; and Exobiology.

The **Space Physiology and Countermeasures Program** is responsible for studying the physiological changes and deconditioning resulting from space flight, developing predictive models and methods for assessment of deconditioning trends, and for developing countermeasures. To accomplish this, the program supports both basic and applied research utilizing ground- and flight-based laboratories. Virtually all body systems are affected by exposure to microgravity. For example, bone loss and muscle atrophy are among the most serious chronic problems, and exercise protocols and other countermeasures will be required as part of an effort to mitigate these

Figure 2
Life Sciences Core Strategy

Fiscal Years	On-Going Programs	Enhancements to Research Base	Missions		SSF Utilization and Support
			Small	Moderate	
1989-1990	Operational Medicine	<ul style="list-style-type: none"> • Microwave Observing Project (SETI) • Soviet Space Station (MIR) • Extended Duration Orbiter Medical Program (EDOMP) (13 days) 			<ul style="list-style-type: none"> • Centrifuge Facility • Crew Health Care System (CHCS) • Space Biology Initiative (SBI)
1991	Research and Analysis Spacelabs/Space Shuttle	<ul style="list-style-type: none"> • NSCORT • Life Sciences Research Groups • Life Sciences Laboratory Equipment (LSLE) 			
1992		<ul style="list-style-type: none"> • Data Archiving 			<ul style="list-style-type: none"> • Biomedical Monitoring and Countermeasures (BMAC)
1993		<ul style="list-style-type: none"> • Biospheric Research (TERRA)* 			
1994		<ul style="list-style-type: none"> • EDOMP (16 + Days) 			
1995 through 2002		<ul style="list-style-type: none"> • Research Community Revitalization 	<ul style="list-style-type: none"> • Spacelab (EDO) Series 	<ul style="list-style-type: none"> • LifeSat (Biology)** 	<ul style="list-style-type: none"> • Life Sciences Space Station Evolution Phase** (Post-Permanent Manned Capability)

* Also part of Mission to Planet Earth

** Also part of Mission from Planet Earth

symptoms. Cardiovascular adaptation to microgravity and readaptation to the Earth's gravitational force also must be understood. Metabolic changes, including calcium metabolism, fluid and electrolyte balances, immunological changes, nutritional factors, and endocrinological problems, need to be investigated also. In order to successfully address the wide variety of issues, the program encompasses several disciplines: cardiopulmonary, musculoskeletal, neuroscience, and regulatory physiology.

NASA's planned missions will involve sending small crews into space for long durations. Such missions require a thorough understanding of behavioral adaptation to space flight and of the conditions that support and enhance human capabilities for living and working productively in extremely isolated, confined and hazardous environments. The **Space Human Factors Program** is concerned with understanding behavioral responses in space and the requirements for designing environments, countermeasures, and support systems that protect and enhance human capabilities, safety, health, and productivity. The research in this program reflects a multifaceted approach to understanding basic human capabilities in space environments, including psychological, social, environmental, perceptual, and behavioral aspects, as well as human machine interfaces, and habitability.

The **Environmental Health Program** is responsible for development of monitoring techniques, remedial procedures, and standards for NASA space missions. Research encompasses those environmental variables that require control and maintenance to assure habitability, including microbiology, toxicology, air and water quality standards, atmosphere pressure, and gas composition.

The **Radiation Health Program** is aimed at establishing the operational basis for the operational protection of humans engaged in the exploration of space, with particular emphasis on journeying to and living on other planetary surfaces. The primary objective of the program is to provide a more precise quantification of the radiation risk to humans undertaking long-duration space flights. Research is supported in the following areas: fundamental response mechanisms to radiation, preventive methods against radiation hazards, characterization of radiation fields, and modeling and theoretical developments for mapping interplanetary environments.

The **Controlled Ecological Life Support System (CELSS) Program** has a commitment to design, construct, and operate a biologically-based regenerative life support system that can eliminate the need for costly resupply from Earth. A system regenerating food, water, and a breathable atmosphere requires investigations and technology development in the areas of plant growth, food processing, waste processing, and recycling, sensing, and control systems. The CELSS Program is structured around six major themes: (1) scientific and technological research to form a knowledge base for development, (2) testing of CELSS prototypes, (3) initial conceptual studies of a ground-based, human-rated CELSS, (4) flight program to determine crop plant productivity, (5) systems control including mathematical modeling, and (6) advanced missions program to examine CELSS requirements for an evolutionary space station.

The **Space Biology Program** is aimed at understanding the effects of gravity on plants and animals at the most fundamental levels, and providing basic knowledge of biological processes through experimentation in microgravity that addresses how gravity is detected by living systems at the cellular level and the force translated into neural, hormonal, or other physiological signals; how plant and animal reproduction are affected over several generations in microgravity; what the relative contribution of gravity is to sensorimotor function; what fundamental biochemical and physical processes govern skeletal formation and resorption; and what turns bone-forming (osteoblasts) and bone-resorbing (osteoclasts) cells on and off. By examining development in space, researchers can address the fundamental role that gravity plays in the process, as well as the biophysical, biochemical and biological mechanisms involved in directing the shape and behavior of organisms and the development and functional competence of gravity-sensitive organs.

There are currently five areas of intensive study in **Biospheric Research**: wetlands research; temperate forest research; tropical forest research; global monitoring and disease prediction; and global studies. Wetlands-related activities involve research to gain an understanding of the role of wetlands as a major source of biogenic trace gases in the atmosphere. In temperate forest research, the thrust is to characterize the contribution of soil and canopy processes to global biogeochemical cycles and to develop mathematical models of these processes. The primary interest in tropical forest research is to understand the contributions of tropical forests to the composition of the atmosphere and the consequences of human encroachment. The goal of global monitoring and disease prediction research is to define environmental factors, habitat, vector distribution, and ecology of insect-borne diseases using spaceborne sensors and related technology. Global studies research integrates remote-sensing

and ground-based data with development and validation of mathematical models of regional, continental, and global biological processes in order to understand the essential biogeochemical cycling aspects of the global system.

Current research in the **Exobiology Program** addresses the hypothesis that life is a natural consequence of the origin and evolution of stars and planets; i.e., that life is part of the natural continuum of physical, chemical, and biophysical processes that started with the origin of the universe itself. Key research components of the ongoing program include the origin of the biogenic elements, the effect of planetary environments and processes on chemical evolution and the origin and evolution of life, and the distribution of life and life-related molecules beyond the Earth.

Flight investigations are conducted on Space Shuttle/Spacelabs, aircraft, and international missions. Scientific research in space has been costly to date, partly because it is often necessary to build new research equipment for each flight experiment, and partly because experiments have to meet stringent limitations on weight, size, electrical power consumption, and environmental conditions. Therefore, for life sciences experiments on Spacelab Life Sciences (SLS), International Microgravity Laboratory (IML), and other Spacelab missions, investigators coordinate their research to minimize the need for hardware duplication. The implementation of this strategy to date has resulted in the NASA space life sciences programs developing flight experiments for unmanned COSMOS biosatellite missions with the U.S.S.R., Space Shuttle middeck locker experiments, and a variety of Spacelab missions, both dedicated to the U.S. life sciences community and in concert with other national and international partners. The Spacelab missions now enable the performance of experiments for up to 10 days on-orbit. A range of analytical capability is provided on these missions, with the primary objective being to perform observations and collect samples and specimens during flight for subsequent Earth-based analyses.

2. Enhancements to the research base

The **Search for Extraterrestrial Intelligence (SETI) Microwave Observing Project**, a 10-year program to probe our galaxy for radio signals of possible extraterrestrial intelligent origin, was initiated to address one of the major questions of the Exobiology Program. Using existing radiotelescopes in NASA's world-wide Deep Space Network and additional telescopes made available by the National Science Foundation and foreign organizations, a targeted search of nearby solar-type stars and an all-sky search will be conducted which will be more comprehensive than the sum of all previous searches. The technology needed to mount the search was developed within the base program, and already appears to have applications outside the space field. Deployment of the initial SETI systems is planned for 1992, with full operations in 1995.

Significant cooperation has been accomplished with the U.S.S.R. through the international participation in the **COSMOS and Mir missions**. These missions provide the much needed access to space flight for the U.S. community, while allowing the Soviet scientists to benefit from U.S. scientific and technical expertise. These activities have enriched the scientific yield and accelerated acquisition of the knowledge base for both sides, while helping to solve operational problems.

The **Extended Duration Orbiter Medical Program (EDOMP)** is designed to develop medical countermeasures for Space Shuttle missions of 10 days and longer. The EDOMP was initiated in 1989 and will have two phases: extension of missions to 13 days; then to 16 days. The knowledge acquired as a result of EDOMP activities will feed into the overall database to support more advanced missions on Space Station Freedom. The extension of Spacelab missions will enable experiment replication on the same flight, thus increasing the scientific and operational return from each mission.

In order to revitalize the academic community's contributions to the space life sciences, a number of **NASA Specialized Centers of Research and Training (NSCORTs)** are being established. The first five centers are focused in gravitational biology, environmental health, bioregenerative life support, exobiology, and radiation health. The NSCORT Program is becoming an integral part of the Division's research and analysis program to advance basic knowledge in the space life sciences and generate effective strategies for coping with, and eventually solving, specific space life sciences problems. The program is expected to further the Nation's

scholarship, skills, and performance in the space life sciences and related technological areas and enhance the pool of research scientists and engineers trained to meet the considerable challenges inherent in the Nation's commitment to prepare for future human space exploration missions. The NSCORT Program is designed to mobilize talent and other resources in academia and industry, with meaningful participation from scientists in NASA and other Federal agencies, and to derive the benefits from concentrated administration and financing in a research and training environment.

A new approach to consolidate and focus NASA field center life sciences activities has been formalized, allowing the designation of **Life Sciences Research Groups (LSRGs)** charged with the responsibility of integrating the research activity of a number of tasks into a coherent research program. In 1991, the first LSRG was formed at the Johnson Space Center in the area of bone and muscle research. The LSRG designation implies that the team is a national resource in a well-defined area of the space life sciences; is involved in a wide spectrum of basic and applied research tasks; and possesses an appropriate set of laboratory facilities and the scientific expertise to accomplish their agreed-upon tasks. LSRGs may have unique research facilities associated with their laboratory. If this is the case, it is expected that such facilities will be operated as national facilities, and will be available for use by the external research community, including other Federal agencies.

Many investigators use NASA **Life Sciences Laboratory Equipment (LSLE)**, an inventory of multipurpose, reusable medical and biological research sensors, and instruments and facilities developed or modified for use in space. Most of the current hardware is quite old, and LSLE replacements and upgrades will provide much needed state-of-the-art capabilities.

A **life sciences data archiving system** is being implemented to facilitate the orderly preservation and dissemination of integrated data sets and specimen samples. The archive system, as currently envisioned, is planned to be accessible through a common network providing controlled access to all investigators.

3. Small missions

Small missions currently in the detailed planning stage include a continuation of the extended-duration Spacelab series. Research will be conducted in nearly all space life sciences disciplines. The primary and secondary emphasis and schedule for each of the planned major space life sciences missions are shown in Figure 3.

4. Moderate missions

A **reusable, free-flying biosatellite (LifeSat)** that enables studies using living biological specimens including plants, rodents, cell and tissue cultures, and other small organisms is currently in the planning stages. In addition to retrievability, this biosatellite will have a unique set of technical capabilities, including access to orbits that the Space Shuttle cannot reach (e.g., polar orbit), extended flights (e.g., 30 to 60 days), and exposure to varying gravity levels (e.g., 0 to 1.5 g). The current program calls for initiation in 1992 as part of the Radiation Biology Initiative (RBI) as described on page 20. Six missions are planned from 1996 through 1998. Space biology research will be accommodated on all these missions. Major enhancement and emphasis upon space biology will begin with the fifth LifeSat mission. Figure 4 shows the planning schedule for launching all small and moderate U.S. and international missions.

5. Space Station Freedom utilization and support

Space Station Freedom (SSF) has great significance for NASA space life sciences programs. For the first time it will be possible to replicate experimental data with appropriate controls and real-time analytical capabilities over extended periods of time. Freedom will provide the means to acquire basic knowledge on mechanisms of gravity perception while paving the way for extended-duration exploration missions with humans. The basic space life sciences research strategy for the utilization of SSF is a "single stream" pressurized laboratory approach. This means that there will be a transition from Space Shuttle/Spacelab EDO missions to Freedom research, and that once a fully outfitted life sciences laboratory is available, there will only be dedicated life sciences Spacelab flights if the science to be addressed can be best accomplished on such missions. Currently there are plans for at least two dedicated Spacelab Life Sciences missions after SSF is available for man-tended operations; however, evaluations are being made of the cost and feasibility of dual compatibility (Spacelab and Freedom) hardware to

Figure 3
Major Space Life Sciences Flight Opportunities

DISCIPLINE	DESCRIPTION	SLS-1 (1991)**	SLS-2 (1993)	SLS-3 (1995)	SLS-4* (1997)	NEUROLAB* (1999)
CARDIOVASCULAR	Cardiopulmonary, fluids, electrolytes	1	1	2	2	
MUSCULOSKELETAL	Bone, calcium metabolism, muscle modification	2	2	1	1	
NEUROSCIENCE	Vestibular physiology, neurophysiology, and neurobiology	2	2		2	1
REGULATORY PHYSIOLOGY	Endocrinology, metabolism, immunology, pharmacology, renal physiology, rhythms	2	2	2	2	2
SPACE HUMAN FACTORS	Anthropometry human - machine interactions performance	2	2	2	2	2
MEDICAL CARE TECHNOLOGY	Surgical workstation, health maintenance facility, diagnostics	2		2	2	
GRAVITATIONAL BIOLOGY	Plant biology, developmental biology				2	2
EXO BIOLOGY	Gas-grain simulation			2		

1: PRIMARY DISCIPLINE EMPHASIS
2: SECONDARY DISCIPLINE EMPHASIS

* PLANNING STAGE
** FISCAL YEAR

Figure 4
Life Sciences Flight Missions
Calendar Year Quarters

	1	2	3	4
1991		SLS-1		
1992	IML-1		SL-J	
1993	SL-D2	SLS-2		
1994	IML-2			
1995		SLS-3	SL-D3/E1*	
1996		RBI (LifeSat-1)*		
1997	SL-E2*	RBI (LifeSat-2)*		
1998	RBI(LifeSat-3)*	SLS-4*		RBI (LifeSat-4)*
1999		LifeSat-5* (Biology)	Neurolab*	LifeSat-6* (Biology)

*Planning Stage

provide flexibility to accommodate additional flight opportunities. Configuration and timing decisions will be in keeping with SSF schedules.

A plan for space life sciences research activities that are of high programmatic and/or operational relevance, are technologically feasible, and can optimally utilize the capabilities to be provided by an evolving SSF has been identified. The guiding principles for phasing the space life sciences operational and research priorities considering the two principal goals of human health and acquisition of science will be:

1. Starting with the Man-Tended Capability (MTC) the Biomedical Monitoring and Countermeasures (BMAC) Program will be phased-in to address operational issues, specifically focused on extravehicular activities (EVA). Suitable gravitational biology research will be conducted.
2. MTC medical care capabilities will be enhanced to support Permanent Manned Capability (PMC) by the deployment of the Crew Health Care System (CHCS) facility.
3. The BMAC Program will be fully operational at PMC to enable progressively longer-duration crew stay times on-orbit.
4. Gravitational biology research will be expanded after PMC, commensurate with added SSF capabilities, to provide an insight into the mechanisms of physiological changes associated with extended exposures to weightlessness.

The Life Sciences Division plans a three-phased implementation strategy for SSF:

PHASE I:	EVA/Human Physiology (Commence with Man-Tended Capability)
PHASE II:	Life Sciences/Life Support (Commence at Permanent Manned Capability)
PHASE III:	Meeting Expanded Science and Operational Requirements

This strategy provides for an evolutionary process of facility development and deployment, with a build-up of on-orbit capability over a 5-year period (1996 — 2001). Each phase builds upon the preceding infrastructure and enhances the capability to perform research to meet a wider range of science requirements.

Phase I: EVA / Human Physiology Research

The primary focus will be the understanding of the physiological responses to repeated extravehicular activity (EVA) and monitoring of human health and the environment of Freedom. Opportunities for such studies will markedly enhance our ability to quantify the physical and physiological demands associated with EVA, thus establishing a foundation for future in-space operational activities, since:

- EVA is an important part of NASA operations - including future planetary surface operations;
- SSF/MTC will offer a unique opportunity for study because of the planned levels of EVA; and
- While ground-based data are extensive, the space-based data set is not fully developed or validated.

Some of the scientific and operational questions to be addressed are as follows:

- Does the "R-value"* used in simulations provide an appropriate measure of medical risk in space?
- Is the N₂ elimination process more efficient in zero gravity?
- Is the bubble formation and elimination process different in zero gravity?
- Does exercise in zero gravity affect the course of the space adaptation process?
- What medical procedures or treatments might be instituted to minimize the risk of bends?

*R value is the ratio of N₂ partial pressure in the tissue before decompression to total suit pressure after decompression

Specific areas of research will include:

Pulmonary — Study of pulmonary function in reduced gravity will determine impact on ventilation/perfusion, including bubble formation and evolution. The initial dependence upon a normoxic atmosphere at 10.2 psi presents an opportunity to collect data on oxygen uptake and nitrogen elimination at this atmospheric composition.

Cardiovascular — Studies will be conducted of alterations in cardiovascular function and cardiac electrophysiology, at rest and during exertion in weightlessness, along with diurnal variation in hormonal, electrolyte and fluid balance.

Anthropometry and Performance — Specific areas for major study include: body segment size change in microgravity and effect on performance. Predictive models of crew activities for subsequent analysis of workloads and training both on the ground and in-flight will be developed.

Metabolic and Musculoskeletal — The time course of changes in muscle strength, endurance, coordination, and fatigability will be studied. Study relative changes in endocrine, body water, fat and muscle mass, and thermal control will be included. Also the potential for in-flight health hazards, such as renal stone formation, water and electrolyte loss, and replenishment requirements will be evaluated, and appropriate work-rest schedules will be established.

Neuroscience — These studies will provide insights into the mechanisms of adaptation as well as a means of predicting and ameliorating neurophysiologic functions during space activity. The studies will include neuromuscular and sensory-motor function, posture, and orientation.

Infrastructure Requirements (Phase I)

1. Equipment to perform pulmonary, cardiovascular, anthropometric, metabolic, muscular, and neurophysiological monitoring during all phases of EVA will require two to three SSF racks (including stowage).
2. Due to requirements to conduct studies during the man-tended phases under a 10.2 psi, normoxic atmosphere, ground-based studies utilizing hypobaric facilities will be required. Current data bases at reduced but normoxic atmospheres are limited or not available in many areas of physiology.

Phase II: Life Science / Life Support

Phase II will commence with the outfitting flight following the deployment of the habitation module and achievement of Permanently Manned Capability (PMC). This phase will build upon the established infrastructure to provide an initial national and international life sciences research capability on SSF, which will include a 2.5m centrifuge facility. The capability will support basic research on plants, animals, and humans, while expanding the ability to test the efficacy of countermeasures (BMAC) necessary to develop an understanding of the biological processes affected by space flight. This will enable us to quantify the negative impacts of adaptation to microgravity and develop operational crew health support capabilities for SSF and exploration missions.

During this phase, biomedical and life support research activities will be initiated to: (1) investigate and verify technologies and medical support necessary to enable an operational program for crew health maintenance during extended stay time on SSF. Included is the development and testing of a fully operational bioregenerative life support system for human exploration class missions; and, (2) expand our understanding of basic human physiology in weightlessness in preparation for space exploration.

In this phase, BMAC will be fully implemented to address the primary challenges that potentially limit the duration of human space flight. Humans have successfully lived and worked in the weightless environment of space —

occasionally for lengthy periods of time. Through observation, data collection, and subjective accounts, we have learned that physiological changes occur that may reduce performance in flight and impair the ability to readapt to a gravitational environment. It should be noted that these data have been collected while countermeasures were in use. Little information exists from only a few individuals who did not use countermeasures or used them only in a partial way. One of the conclusions which can be made from these observations, however, is that the current generation of countermeasures is only partially effective.

Some of the known responses of physiological systems to space flight are summarized below:

- Bone density is reduced.
- Muscle strength and mass are reduced.
- Neurological changes affect gait, stability, and cardiovascular function on return to a gravity environment.
- Body fluid volume and blood volume, including red blood cells, are reduced.
- Orthostatic intolerance is manifested on re-exposure to gravity.
- Space motion sickness is experienced during the first week of space flight by about half of the crewmembers.
- Cardiac arrhythmias are experienced during extravehicular activity.
- Immunity is impaired after prolonged space flight.
- Absorption of medications is impaired.
- Hormone blood levels and function are altered.

Countermeasures that address problems of short-duration flight are used as standard medical protocol during Space Shuttle flights of ten days or less. These include the consumption of salt and water prior to landing, the wearing of anti-g suits during landing to improve tolerance to orthostatic stress, and drugs and behavior modification to reduce space motion sickness. During longer flights, such as the U.S. Skylab missions and the Soviet missions on Salyut and Mir, exercise (often for several hours each day) has been used as a countermeasure to muscle atrophy and loss of aerobic capacity. These countermeasures are partially successful in shorter flights. However, the extended missions will require significant improvement in these countermeasures in terms of ease of use and efficacy. The countermeasures currently used address the symptoms, not necessarily the causes.

Questions relevant to the development of an effective countermeasure program will be addressed during this phase of research on SSF. Some of these questions can be summarized as follows:

- What are the kinetics of bone loss during space flight?
- What is the time course of bone loss; is it a self-limiting function?
- How much bone loss can be tolerated and full recovery occur?
- Will the increased blood calcium cause kidney stones?
- What are the best countermeasures to bone loss?
- What cellular and biochemical changes occur within sedentary muscle?
- What is the best form of exercise to maintain adequate muscle mass?
- What combination of fluid loss, neurological and reflex changes, muscle loss, and cardiovascular changes causes orthostatic intolerance?
- Are normal circadian rhythms disrupted in space without the normal light/dark cycle? What effect does this have on health and performance?
- Are cardiovascular, pulmonary, and other physiological responses to exercise different in weightlessness and reduced gravity; if so, what are the implications for work on the Moon and Mars and return to Earth?
- Are neural communications disrupted in weightlessness, and, if so, how can they best be reestablished?
- What immunological deficits result from prolonged stress and isolation?
- What impairments occur in absorption and metabolism of nutrients?
- What are the cumulative effects of repeated exposures to weightlessness?
- Are brief exposures to artificial gravity an appropriate countermeasure to physiological changes observed in space flight?
- Should a human centrifuge (artificial gravity) be included on a planetary vehicle?

Continuation of our program of basic research on the ground, aboard the Shuttle, and on Space Station Freedom is essential to the development of optimal countermeasures.

Basic research in the space life sciences will be conducted on SSF utilizing the Centrifuge Facility and three "generic" facilities consisting of the Gravitational Biology Facility, CELSS Test Facility, and the Gas-Grain Simulation Facility. These facilities are being furnished through the Space Biology Initiative (SBI).

The Centrifuge Facility for SSF is expected to be the single most important research tool for space life sciences. This facility will provide controlled levels of artificial gravity for experiments using plant and animal subjects designed to separate the effects of weightlessness from other environmental factors. Controlled experiments addressing long term adaptation changes and mechanisms; fractional gravity studies to determine g-sensing thresholds (simulate Moon and Mars); and validation of medical care procedures. To date, only very small centrifuges (a fraction of a meter in diameter), accommodating only a limited range of specimens, have been flown on Space Shuttle/Spacelab missions and on Soviet biosatellites and space stations. The Centrifuge Facility will provide a major technological advance to enable investigations on a variety of test subjects over durations representing all or a significant portion of an organism's life-span.

The Centrifuge Facility and the three "generic" facilities will enable the following investigations to be conducted:

Plant Biology — All scientific experiments in plant biology will utilize on-orbit, one-gravity control populations. Several of the classes of experiment, dealing with gravity thresholds and gravity sensors, require a variable-gravity exposure facility capable of simultaneously exposing paired specimen samples to both experimental levels and one gravity.

- a. Determining the capability of plants to reproduce in space over a time span of several generations has long been considered of high priority. The man-tended and free-flyer phases of SSF will follow schedules that could provide logistical and observational support for such experiments. Typical seed plants with long life cycles will be employed, with growing conditions capable of producing viable offspring.
- b. Effects of the space environment on metabolic functions in plants have been identified, but detailed studies have not been completed. Of special interest is carbohydrate synthesis and the formation of support polymers.

Cellular Biology — Studies utilizing cultured cells and tissues will be conducted to address the influence of microgravity on function and behavior of microorganisms, animal and plant cells (growth and proliferation, production of biomass, metabolite production and secretion). Equipment required for such studies is self-contained, has low power requirements, and can operate within an external environment of normoxic 10.2 psi. In many instances, small centrifuges can be designed to provide adequate one-gravity controls for the cultured samples.

Animal Biology — Each of the following areas will utilize inflight microgravity habitat populations matched with one-gravity control habitat populations for extended periods of time.

- a. Investigations will address reproductive biology, embryonic and early maturational development, genetic research, brain and nervous system research, and skeletal/biomineralization. One-gravity controls must be available for proper science return.
- b. Multigenerational studies with invertebrates will address life cycle biorhythms, aging, metabolism, cellular changes and space-flight effects on mutant strains.

Radiation Biology — The biological effects of extended exposure to the Space Station Freedom trapped radiation environment can be studied by continuous exposure of a variety of plant, animal and cellular species. These studies will provide important data for predicting health consequences of long-term habitation, and insight into biological manifestations and environmental effects operant under conditions of space flight.

Exobiology— The science community will be provided a facility capable of simulating and studying small-particle and gas-grain interactions. In addition, this facility will accommodate investigations in exobiology, planetary science, atmospheric science, and astrophysics.

Environmental factors and regenerative life support systems requirements will be addressed during this phase. The development and testing of an effective environmental monitoring and control system capable of detecting a wide variety of sources and types of contaminants will be conducted, thus determining the optimal habitability requirements for extended missions. Bioregenerative life support systems, based on higher plants, may likely be used on future missions in orbit, in transit and on lunar and planetary surfaces. The Controlled Ecological Life Support Systems (CELSS) Test Facility will study plant growth and crop productivity in order to develop stable and reliable CELSS. Investigations will determine the conditions that support maximum crop productivity and energy conversion efficiency for higher plant populations in microgravity.

Infrastructure Requirements (Phase II)

Following deployment of the habitation module, subsequent outfitting flights will phase in the Centrifuge Facility, BMAC Facility racks and CELSS Test Facility and a specimen chamber refurbishment unit, and the Gas Grain Simulation Facility. The two to three racks previously utilized in the MTC will be replaced and augmented with elements of the BMAC facilities currently estimated to require a minimum of four racks.

Phase III: Meeting Expanded Science and Operational Requirements

The Life Sciences Division has invested significant resources in planning for operations of an International Life Sciences Research Facility on SSF. Such a facility is planned to support continuous scientific investigations for more than 20 years and meet the requirements for:

- Research devoted to indepth study in each medical and biological discipline over dedicated periods of time (up to 6 months)
- Establishing a capability to address medical issues which will enable exploration missions with humans.

By the year 2001 the following capabilities will be available on the SSF:

1. **The Gravitational Biology Facility (Centrifuge)** will provide the generic equipment necessary to support the study of gravity sensing and response mechanisms across a range of gravity levels to understand the role that gravity plays during embryonic development and maturation of animals and plants. The facility will provide sample collection, analytical instrumentation, data management, and other support functions for gravitational biology experiments. The Gravitational Biology Facility also will contain generic support equipment, such as computers, required by other onboard life sciences research facilities. Understanding the mechanisms underlying responses to weightlessness will enable the refining of human countermeasures.
2. Experiment accommodated by the **CELSS Test Facility** will enable the systematic development of the capability to control, monitor, and evaluate the growth of crop plants. This Facility will be used to perform chemical and bioregenerative subsystems to determine means to use plants for supplementary food production.
3. The **Exobiology Facility** (also known as the Gas-Grain Simulation Facility) will be used to simulate and study fundamental chemical and physical processes such as the formation, growth, accretion, and interaction of clouds, dust grains, and other particles in microgravity. Processes observed in the Exobiology Facility will help explain the dynamics of the formation of the universe.
4. The **Biomedical Monitoring and Countermeasures (BMAC) Program** will provide the countermeasure validation protocols and health monitoring to ensure that the countermeasures are effective using specific

health indices in-flight on a routine basis. This program augments and continues the EVA/human physiology capability. Based on the findings from the BMAC program, supporting biological studies and additional enhancements to the biomedical facilities might be required to initiate the validation of procedures on SSF required for an exploration mission to Mars.

5. The **Crew Health Care System (CHeCS)** will provide for SSF operational needs during the first 5-10 years of Permanently Manned Capability. CHeCS will be fully operational by PMC. The subsystems of CHeCS are the Health Maintenance Facility (HMF), the Exercise Countermeasure Facility (ECF), and the Environmental Health System (EHS). As a supporting facility to CHeCS, a hyperbaric capability will be provided. This is necessary for treatment of decompression sickness (bends), which could occur during EVA operations. In addition to these provisions, studies to define an Assured Crew Return Vehicle (ACRV) will be available. This vehicle will function as a "life boat" or as a crew return vehicle if required. CHeCS will support the ACRV by stabilizing a patient prior to transport. ACRV will allow terrestrial treatment at appropriate hospitals for serious injuries or illness that cannot be adequately cared for onboard SSF.

Infrastructure Requirements (Phase III)

Based on the findings from research over the first five years after PMC, supported with ground-based modeling studies, additional facilities, such as a human-rated centrifuge and special bioinstrumentation equipment, might be deployed.

C. STRATEGY FOR MISSION FROM PLANET EARTH

This section describes augmentations to the core program that will be required to enable the Mission from Planet Earth (MFPE). While no single mission set with clearly enunciated schedules has been selected, initial planning has determined mission destinations, established priority sequences for mission implementation, defined general mission objectives, and identified key programs and supporting elements. The sequence of SSF, return to the Moon and evolution to self-sufficiency, followed by the manned exploration of Mars, defines the nature of the critical areas for research efforts to establish life sciences/life support requirements.

Human missions beyond low Earth orbit pose an enormous challenge to the space life sciences. While the augmentation to the elements of the core programs described above are essential to any such undertaking, additional major issues also must be addressed. The proposed missions to the Moon and Mars, ranging in length of up to 3 years, will expose crewmembers to a number of known and unknown hazards. The key areas of uncertainty affecting human physiology involve the effects of exposure to radiation and of extended stays in microgravity and reduced gravity. More efficient life support systems to provide closure of air and water loops and food production, including *in situ* utilization of resources, are needed. Another critical component is adequate medical care and health maintenance support. Human factors considerations will be pivotal in the ability of the crews to function effectively, in terms of both crew selection, interpersonal relations, man-machine interface, and habitability.

1. Physiological Deconditioning and Countermeasures

Gravity has shaped (or influenced) the evolution of most living things on Earth. Adaptation to microgravity represents the body's response to the lack of certain stresses, using mechanisms which were shaped in a terrestrial setting. The Skylab Program permitted the first detailed studies of this adaptive process, and the Soviet space program has collected data for stays of approximately one year on orbit. The U.S. and Soviet programs have shown that spaceflight exerts a significant and complex influence upon human physiology, leading to a varied range of adaptive (and maladaptive) responses, which if not curtailed by the use of countermeasures, can lead to medical problems. These biomedical manifestations may vary in nature according to the duration of exposure and type of countermeasures used. This process of adaptive responses, termed "space-flight deconditioning," poses real risks for compromising mission objectives, if not adequately controlled.

Changes in human physiology must be understood in order to modify the course of space flight deconditioning and enable the delivery of medical care in space (acute medical care decisions are often based on changes in underlying physiological indices). Satisfactory resolution of the medical and technical unknowns in this area will

require an active program of ground-based studies, as well as inflight investigations. To date, our experience with long-duration missions, comparable in duration to the length of time to reach Mars, is quite limited. Figure 5 depicts the cumulative number of crewmembers who have flown missions of different duration. The majority of U.S. and U.S.S.R. astronauts have flown missions of less than 15 days in length, thus attesting to the inadequacy of currently available biomedical data on long-duration missions which could lead to the development of modern countermeasure systems.

Another concern involves the effects of partial gravity on a crewmember already deconditioned by exposure to microgravity. The significant commitment of time and resources which will precede the initial Mars landing makes it imperative that the crew have adequate physiological reserve to perform assigned duties. While readaptation to Mars gravity (.38 g) is not anticipated to be as pronounced as return to the Earth's 1-g environment today, the understanding of fractional-g physiology is essentially non-existent, preventing an assessment of the relative medical risks.

If the deconditioning resulting from extended stays on planetary surfaces is not adequately counteracted, even minor negative trends, operating over extended periods of time (such as 600 days on Mars), would have the potential of resulting in physiological decompensation on return to 1-g. It is critical that the physiology of deconditioning and readaptation to various g environments be understood well enough to assure that the crew would not suffer serious medical consequences upon return.

If exercise and other forms of countermeasures should prove inadequate or operationally infeasible, artificial gravity may be required. Consequently, in addition to the continuation of an expanded BMAC type program, a parallel research effort to define requirements for artificial gravity systems should be conducted.

2. Radiation Health

One of the major unknowns for any manned mission outside the Earth's magnetosphere and for exploration and habitation of the lunar and Martian surfaces is the radiation health risk. Specifically, the level of biological damage produced by galactic cosmic rays and solar particle events, must be quantitatively assessed. Galactic cosmic rays are the major source of continuous radiation outside the magnetosphere. Even though galactic cosmic radiation has a relatively constant intensity and is fairly well-characterized, it has the highest uncertainty level with respect to risk assessment. This is due mainly to the large uncertainties in the biological effects of primary and secondary charged particles. The all-pervasive galactic cosmic radiation burden represents a long-term excess cancer mortality risk. There is currently no appropriate model for early or late biological effects of this radiation.

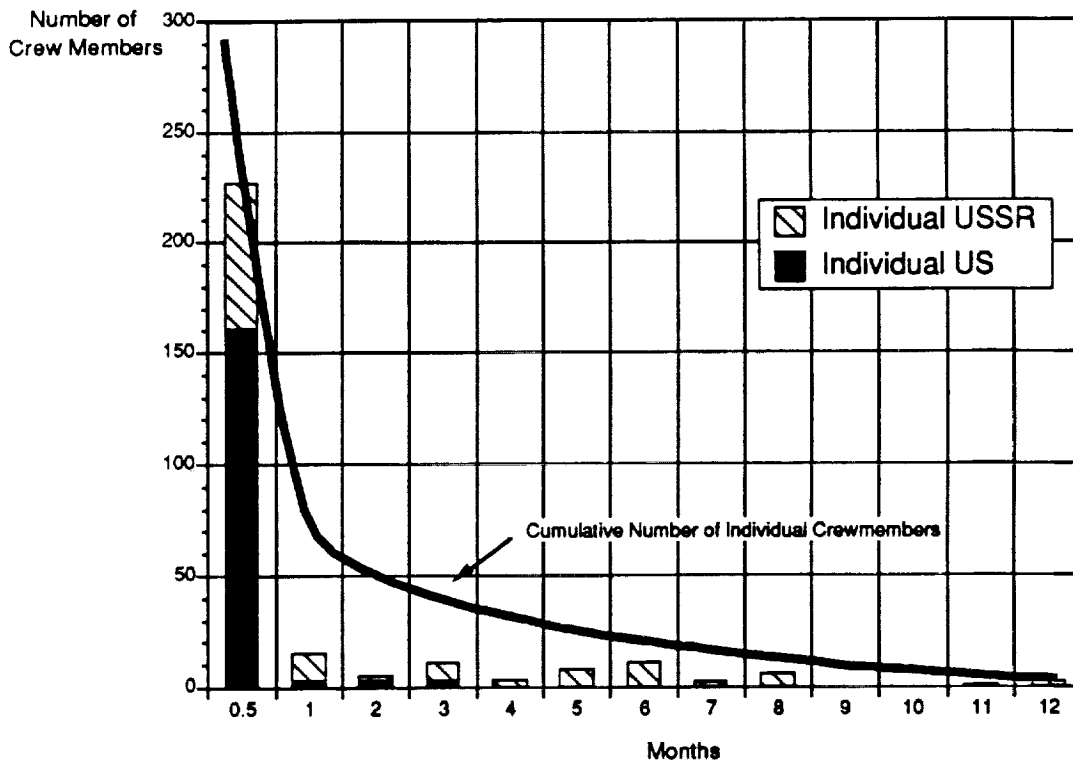
The solar particle events are lower in energy and easier to shield against than the galactic cosmic rays. However, they are highly variable in energy and intensity from event to event, and for anomalously large events represent a lethal, acute space radiation hazard. There is at present no adequate model that can predict either the occurrence, energy, or relative intensity of solar particle events.

The MFPE program requires a definitive risk assessment of space radiation hazards and enabling science validation through ground- and space-based research. This research program is necessarily complex, since it requires a multidisciplinary integrated approach in solar physics, nuclear physics, theory (modeling), radiobiology, and probability risk assessment. Impacts due to radiation issues on spacecraft design, habitats, and mission planning must be assessed with a high level of confidence to meet MFPE milestones. Robotic unmanned Mars missions, with sample return capability, can provide significant information on the SPE events and physical environmental conditions which will be encountered by humans on such missions.

A program entitled the *Radiation Biology Initiative (RBI)* has been initiated to explore research to assess radiation risks and determine how best to manage those risks. The implementation of the RBI Program entails an interagency effort between NASA, DOE, and DOD research programs in order to utilize existing facilities and scientific manpower in a timely manner. Enabling science and technologies therefore require ground- and space-based facilities and programs which have three to five-year lead times to be in place and fully operating.

While an expanded ground-based program could develop a great majority of the scientific basis for predictions of space radiation hazards and shielding requirements, these predictions are based on simulating the space radiation environment with a relatively small number of particles, at a restricted number of energies. Before such

Figure 5
Number of U.S./U.S.S.R. Crews In Space



predictions can be used for the management of space radiation risks, they need to be validated in the space environment, where all particles, at all energies, are incident from all directions. Thus, the space experiments are critical for a full verification of the predictive models and rightfully constitute the major cost of the overall program. The LifeSat biosatellite proposed as a new start for FY 1992 will expand previous capabilities in several fundamental aspects:

1. **Radiation Environments:** the orbits accessible to LifeSat allow it to expose biological samples in environments outside the Earth's magnetic field, where the galactic cosmic rays effects become comparable in magnitude to the trapped radiation effects; the trapped radiation belts can also be used as a source of mixed radiation for studies of biological interactions with weightlessness.
2. **Flight Duration:** the 30-60 day duration of LifeSat missions enables it to expose biological samples and particle spectrometers to radiation doses sufficient for quantitative experiments capable of being validated at the 10-20% level.
3. **Payload Volume:** the 1 cubic meter payload that LifeSat can accommodate, together with the flight duration factors, makes it possible to carry sufficient sample sizes of cells in culture for statistically significant validations and to perform sensitivity analyses of factors entering into prediction of the expected results.
4. **Recoverability:** this enables radiobiological experiments to be executed without placing undue requirements on power and telemetry that would exceed the constraints on this type of project. Recoverability also makes postflight studies possible. For example, cells transformed in flight can be transplanted into immunosuppressed mice to titrate their carcinogenic potential. Such experiments provide at least an indirect way of observing animal responses to space radiation.

3. Medical Care Systems

Within the U.S. space program, inflight medical illness has resulted in only minor mission impacts, presumably due largely to the good health, relatively young age of the astronaut corps, and the limited length of missions. In contrast, the Soviet space program, whose missions are often lengthy, has been affected, on occasion, by inflight medical contingencies, resulting in either a mission abort or significant replanning. While predicting the probability of medical illness or inflight injury is difficult, it is reasonable to assume that medical contingencies can occur at any time in the course of an ambitious and sustained exploration program.

The approach to inflight medical care is one of risk management. Since it is not cost effective to duplicate the entire capability of a modern hospital onboard a spacecraft (or surface habitat), the general principles underlying terrestrial medicine should be adhered to, within the context of existing program constraints. Crew health can conceivably be affected by a number of factors, including: a) preexisting medical risk; b) physiological deconditioning, which if not corrected may result in or aggravate a medical event; c) occupational injuries due to inherently hazardous operations; and d) risks secondary to spacecraft environmental factors, especially those due to failure or degradation of life support systems.

The primary considerations affecting the design of an inflight medical care system include the degree of remoteness from Earth (and subsequent limitations on medical transport), nature of operations, degree of hazard involved, crew size, mission length, and degree of acceptable risk. Eventual development of an effective medical care system for exploration will be dependent upon advances in several key areas. The principal areas of concern include the following:

- Delivery of medical care in space will be dependent upon an understanding of space-flight physiological deconditioning and upon the development of procedures and protocols for clinical care in reduced and microgravity environments.
- In addition to developing an adequate understanding of space-adapted physiology, knowledge of how the body responds to pathological conditions (i.e., shock or trauma) in microgravity will be required in order to practice space-based medicine. This data will build upon an understanding of the "normal" space-adapted physiology, and will be accomplished by means of a focused research program utilizing SSF.
- Adaptation of "off the shelf" medical technology will be the principal hardware thrust; however, there are certain key capabilities which the program will need. These include computer-aided medical diagnosis, extended life pharmaceuticals, blood substitutes (or freeze-dried blood), and compact imaging and diagnostic systems. Advances in these areas would be very significant in terms of their applications within the medical field.

Significant progress in the development of inflight medical care systems can be made by use of the Space Shuttle as a platform for the development and validation of medical hardware. Modest, sustained effort will allow early implementation of terrestrial medical testbeds, joint development of certain critical medical technologies with the SSF Program, development of medical care procedures/protocols utilizing "zero-g" aircraft, and development of a university-based telemedicine developmental laboratory to refine space telemedicine applications. Studies to clarify overall medical care requirements for various missions and hyperbaric treatment will be included.

4. Life Support Systems

Conducting operations in space requires that provisions be made for protecting people from its inhospitable environment. Human physiology possesses a remarkable degree of adaptability, but humans can only survive in an environment characterized by rather narrow thermal and atmospheric limits. Furthermore, adequate food and water are required to sustain life. The consumables needed to sustain life can either be brought from Earth or, with the right technology, created in place from wastes or *in-situ* resources. This tradeoff between resupply, regeneration, and manufacturing is embodied in the concept of loop-closure. U.S. space programs to date have employed open-loop system design, with no reuse of waste products (i.e., carbon dioxide, waste water streams, biological wastes, etc.), which are stored for return to Earth or are vented overboard from the spacecraft. However, the type of closed-loop systems critical to the success of the exploration program have never been developed. Creation of closed-loop life support systems based on regeneration of waste products represents a radical departure from the existing experience.

SSF will be utilized to perform enabling research and to gain operational experience of importance to the MFPE. Of particular interest will be the Biomedical Monitoring and Countermeasures Program and the scientific research made possible through the use of the Centrifuge Facility and the facilities provided by the Space Biology Initiative.

As with all elements of Mission from Planet Earth, *in-situ* science will become progressively more sophisticated as the program proceeds. On both the Moon and Mars, the capabilities of the scientific facilities will be expanded.

Research elements would include a focused effort to address psychological issues (crew selection, effects of extended isolation and confinement, group dynamics, etc.), use of analog environments for evaluating design concepts and studying crew dynamics, and the use of terrestrial testbeds. The design requirements of surface habitats and a Mars transfer vehicle are unique and will require dedicated testbeds. These facilities will be utilized for testing operational protocols and system hardware, and for an assessment of habitability. Microgravity validation of human factors concerns will utilize SSF and potentially a precursor Mars transfer vehicle. The precursor Mars transfer vehicle will be a microgravity testbed to refine and validate the design and operational capabilities of the Mars transfer vehicle, and will allow progressive upgrades of components as operational experience accumulates.

Traditionally analog and simulation facilities have played an important role in the definition and design of space missions. The complex nature of the challenge and the many options that will be available as humans embark on exploration missions beyond Earth orbit will require that, in the early stages, simulation facilities be established on Earth. The use of analog environments that approximate in important ways those environments to be encountered on future space missions will enhance our understanding of human performance and supporting technology in remote and isolated settings. Simulation facilities located in analogous settings to long-duration space flight or outposts on the Moon and Mars include undersea habitats and Antarctic research sites.

6. Outposts on the Moon and Mars

Although the specific pace and implementation plans are not yet defined, NASA's preliminary approach to the development of outposts on the Moon and Mars consists of four phases. The first, robotic exploration, obtains data to assist in the design and development of subsequent human exploration missions and systems, demonstrates technology and long communications time operational concepts, and dramatically advances scientific knowledge of the Moon and Mars. The second phase, outpost emplacement, emphasizes accommodating basic human habitation needs, establishing surface equipment and science instruments, and laying the foundation for future, more complex instrument networks and surface operations by testing prototypes of later systems. The third phase, consolidation, further expands these capabilities, and the fourth phase, operation, entails a steady-state mode with the maximum possible degree of self-sufficiency.

Space life sciences research to support human exploration will progress incrementally as the program proceeds. In the early stages, SSF will serve as a controlled testbed for studying extended-duration human habitation of space and for developing and validating systems and elements, such as habitation and laboratory modules and life support systems, to be used later on the Moon and Mars. Preparation for human missions to Mars will require a series of robotic missions after the Mars Observer to support and verify landing site selection, identify hazards to human explorers, and prepare for science experiments conducted by the crew.

SSF will be utilized to perform enabling research and to gain operational experience of importance to the MFPE. Of particular interest will be the Biomedical Monitoring and Countermeasures Program and the scientific research made possible through the use of the Centrifuge Facility and the facilities provided by the Space Biology Initiative.

As with all elements of Mission from Planet Earth, *in-situ* science will become progressively more sophisticated as the program proceeds. On both the Moon and Mars science capabilities should begin with local human exploration complemented by unmanned rover traverses and be followed by the emplacement of initial science instruments. Later, more advanced research facilities can be built, including pressurized life sciences testbeds to be used for basic and applied life sciences research. Upon the initiation of the emplacement phase of the lunar outpost, an additional focus for life sciences research will be on systems developed on the Moon itself. Early systems will be used to establish prototypes for long-term habitation, and later habitats will provide additional space for increased biomedical and life sciences research. The facilities will be used to simulate the eventual long-term stays anticipated for a Mars mission. Later, space life sciences research in preparation for Mars missions can be conducted at the lunar outpost. Advanced medical and life support technology development of systems to protect and support human space travelers must also be conducted. Areas of concern include radiation protection, reduced gravity countermeasures (including artificial gravity), medical care, life support (including EVA), and resolution of behavioral and human factors issues.

There are critical gaps in our understanding of exobiology that can only be filled by space exploration, including missions to the Moon and Mars. Exploration missions to the Moon will permit the collection of solar, interstellar, and interplanetary dust particles that will reveal the cosmic history of the biogenic elements and compounds. Simulations of dust-grain chemistry, studied in the lunar environment, will further our understanding of the synthesis of complex organic molecules in space. Exposure of terrestrial organisms will allow extensive studies of the survivability and adaptation of life in the space environment. Perhaps the most important benefits will be the use of the lunar surface as a platform for observations of organics in planetary atmospheres and interstellar environments. Analyses will be performed on samples from the polar regions and the deep subsurface for possible prebiotic molecules delivered by cometary impact, while samples from a variety of lunar craters will significantly improve our understanding of the impact of events that have affected the evolution of complex life on Earth. Using the lunar far side to search for radio signals from intelligent species beyond the solar system will extend similar terrestrial observations into domains inaccessible from Earth.

Exploration missions to Mars will provide a unique opportunity to understand the role of life in the evolution of the terrestrial planets. The role of life in determining planetary evolution is one question whose answer could have immediate consequences in understanding global change on Earth. On Mars, exobiologists will seek to understand whether life ever arose, and if not, why not? Identifying differences between chemical evolution on Mars and Earth will enhance our understanding of life's origins. If there was life on Mars, then studying the fate of that life and its possible survival into the present will be the major science driver for the exploration of the planet.

There is considerable evidence that Mars had liquid water on its surface at one time. It is possible that life originated on Mars during a wetter early period. Understanding the history of water on Mars is a key requirement for finding sites in which biological activity may have occurred, and in which a record of that activity is recorded. Early robotic missions are critical for addressing the question of extant life on Mars and for laying the foundation for studies of the existence of life during an earlier period. Mars Observer data will reveal information about water, mineralogy, and the structure of the planet. Instruments with an analytical capability to measure evolved gases, electrical properties of the soil, and chemical, elemental, and isotopic composition need to be developed. Future missions will also require instrumentation to search for and select samples for terrestrial analysis for extinct and extant life, including imaging devices, mass spectrometers, and increasingly capable sample acquisition devices.

Earth-based research will permit effective understanding of the data returned from the exploration missions. Terrestrial analogs of the Mars environment (e.g., the Antarctic, simulation chambers, etc.) will be used to develop microanalytical instruments and laboratories for exobiological analysis of returned samples, to better understand the chemical properties of the soil and its biological potential, to learn how to detect fossils in sediments that once harbored life, and to apply the lessons learned at Mars to our questions about how life originated on Earth. Young scientists who will go on to address these questions must be trained to enable future work on the Martian surface. Manned operations on Mars will allow analysis of elements, organics, oxidants, and gases, and extensive microscopy to significantly enhance the search for signs of life. Iterative, real-time interaction between the scientist and Mars may be essential to a full understanding of Mars exobiology.

Key programmatic elements of the space life sciences strategy for the Mission from Planet Earth are outlined in Figure 6. The status in key space life sciences areas as it pertains to extended-duration human exploration missions is illustrated in Figure 7.

Figure 6
Mission From Planet Earth Strategy

PHASE	MEETING HUMAN NEEDS	ROBOTIC EXPLORATION	IN SITU SCIENCE
Robotics and Space Station Freedom	Radiation Biology Initiative (LifeSat)* Space Biology Initiative** Biomedical Monitoring and Countermeasures** Advanced Medical Technology Development Life Sciences Test-Beds for Lunar Outpost	Mars Observer Mars Environmental Survey (MESUR)	Space Biology
Lunar Emplacement and Mars Robotics Lunar Consolidation	Human Factors Life Support Systems Medical Care Systems Health Maintenance System	Mars Sample Return with Local Rover Mars Site Reconnaissance Orbiter Mars Rovers	Lunar Exobiology Life Sciences Pressurized Laboratories
Lunar Operation and Mars Emplacement	Mars Life Sciences Test-Beds Mars Life Support and Medical Systems		Mars Exobiology

* Element of the core program

** These core elements will require enhancement in exploration missions

Figure 7
Readiness in Key Life Sciences Areas

	CRITICALITY	FACILITIES	LEAD TIME (YEARS)
L O W	• Radiation • Life Support • Human Factors	High	Flight & Ground 10
M E D I U M	• Countermeasures • Medical Care • EVA	High	Flight 5 to 15

D. STRATEGY FOR SUPPORT TO MISSION TO PLANET EARTH

The Biospheric Research Program combines space flight and airborne observations with ground-based research to determine how living and non-living elements of the Earth are linked by physical, chemical, and biological processes. These processes are integrated over the entire planet by the land, atmosphere, oceans, and sediments to form a system called the biosphere. The core Biospheric Research Program is dedicated to understanding how biological and planetary processes interact, and how, in conjunction with the environmental effects of human activity, these processes are affecting the long-term habitability of the Earth.

The Biospheric Research Program has developed a new research initiative, "Terra." The goal of this initiative is to lead to an understanding of population and community dynamics using remotely sensed data. Terra represents the Life Sciences Division's contribution to NASA's overall program in Earth System Science. The planned program will exploit remote sensing technology, including Earth Probes and the Earth Observing System (Eos), to increase our understanding of ecological interactions. The major objectives of Terra are to:

- Continue and extend present studies in biogeochemical cycling.
- Support a new emphasis on research at the population and community level using remote sensing.
- Enhance support for applications of population-level studies to disease-vector populations.
- Promote development of remote sensing expertise in the ecological community.

Through Terra and associated activities, the Biospheric Research Program will implement goals noted in the Ecological Society of America's sustainable biosphere initiative, and the reports "Earth System Science: A Closer View" (NASA Advisory Council) and "Global Change in the Geosphere-Biosphere" (International Geosphere-Biosphere Programme).

The Biospheric Research Program has also undertaken the planning and coordination of the Freshwater Initiative, a cooperative interagency program being organized under the framework of the Federal Coordinating Council for Science, Engineering and Technology-Committee on Earth and Environmental Sciences. The Freshwater Initiative is designed to acquire a predictive understanding of freshwater ecosystems and resources that can be used to improve detection, assessment, and prediction of environmental effects, and to develop effective management approaches and mitigation alternatives for potential global change scenarios.

E. DECISION RULES FOR INTEGRATING OVERARCHING INITIATIVES

The process for establishing priorities and sequencing the missions that contribute to overarching initiatives is determined by the thematic relationship the space life sciences goals and objectives have to each initiative and the budget level available in support of the initiative. Though some programs will be refocused to support such initiatives, preservation of the core science program vitality will require an enhancement of the resources historically available to the program, especially in the area of Biospheric Terra and Freshwater Initiatives. The implementation of missions dedicated to the Mission from Planet Earth will require resources beyond the core program level. The strategy to expand elements of the core program that make significant contributions to the Mission from Planet Earth, such as the Space Biology Initiative, the Biomedical Monitoring and Countermeasures Program, and the Radiation Biology Initiative (LifeSat), will be dependent upon NASA emphasis and availability of resources, matching funding pace to implementation schedules. Without such enhancements, these elements will remain in the science- or mission operations-driven, integrated queue.

In undertaking significant new mission initiatives in support of Mission from Planet Earth, the Life Sciences Division will assess their relevance to and impact upon the balance of the overall science program and enabling themes, and the capability of the institutional infrastructure and the scientific community to accomplish them.

The decision rules are:

1. Match the implementation schedule of mission initiatives to the pace at which NASA and the Nation proceed.
2. Establish an implementation schedule compatible with the technological maturity of the mission and with the infrastructure capability to deliver.

F. THE PLAN FOR 1992

The Life Sciences Division's plan for FY 1992 is discussed below, grouped by several broad categories.

1. Flight Programs

Several *Shuttle Spacelab missions* will be supported in FY 1992. Among these is International Microgravity Laboratory 1 (IML-1), of which approximately 50 percent of the payload relates to space life sciences. The focus of U.S. activity on IML-1 includes studies of plants, neurovestibular changes, human performance, radiation and cellular differentiation.

Work will continue on the *Extended Duration Orbiter Medical Program (EDOMP)*. The first extended duration (13-day) Shuttle flight is currently planned for USML-1, in 1992. At that time, approximately 100 Detailed Supplemental Objective (DSO) experiments will have been conducted on missions of different durations to determine acceptable parameters for maintaining crew health and safety on USML-1 and future extended-duration missions. Development of exercise hardware will be completed in FY 1992 and inflight evaluations will be conducted leading to alternative countermeasures. An improved anti-g suit and operational procedures will undergo flight evaluation and the new Baseline Data Collection Facility will be completed and utilized.

In FY 1992, development of upgraded replacements for the *Life Sciences Laboratory Equipment (LSLE)* for Space Shuttle use will accelerate, as many items of existing hardware, some in use since the early 1980's, are phased out.

Efforts will continue on definition and development of experiments previously selected through the Announcement of Opportunity (AO) or NASA Research Announcement (NRA) process and focused on hardware that will be flown on several future Spacelab/Shuttle missions in FY 1992 and beyond, i.e., Shuttle mid-decks secondary payloads, the Japanese SL-J mission, the second dedicated life sciences mission (SLS-2), the German D-2 mission, IML-2, and SLS-3. Collaboration with the Soviet Union on its COSMOS biosatellite program will continue with joint research on a COSMOS flight in 1992. Additionally, opportunities will be pursued to utilize the Soviet Mir for some research activities and hardware verification. Detailed definition and hardware development will continue on an integrated centrifuge facility for SSF.

Activity will continue in the *Space Biology Initiative* program to determine how biological research can be accommodated on SSF, as well as to define instrument and facility requirements. Studies will identify unique scientific and hardware transition requirements from continuing Spacelab flights to SSF operations. In addition, technology assessment, advanced technology development, hardware design and development, and experiment definition and planning will be performed.

2. Radiation Biology Initiative (RBI)

The Radiation Biology Initiative (RBI) will enter a new phase of development, as activity will be expanded at the Lawrence Berkeley Laboratory (LBL), focusing on ground-based simulation of space radiation elements. Plans for the use of the Bevatron Facility at LBL or the Booster Facility at the Brookhaven National Laboratory will continue, as will science definition. The LifeSat spacecraft will begin Phase C/D activities, leading to an initial launch in 1996. Activities in FY 1992 will support spacecraft contract award in the spring of 1992, followed by initial design and early development.

3. Research and Analysis (R&A)

The research and analysis activity supports space life sciences program goals of advancing knowledge in all areas of space life sciences and developing medical and life support systems that enable human habitation in space.

The *Space Physiology and Countermeasures Program* will focus on the study of chronic problems associated with extended durations in space. Information will be collected on occupational exposure in microgravity on each Shuttle flight and potential countermeasures will be evaluated, especially in the areas of vestibular dysfunction,

cardiovascular deconditioning, and musculoskeletal atrophy. This information will be used in the research program to optimize crew performance and to develop countermeasures for extended manned missions.

The **Space Human Factors Program** will continue the development and testing of procedures, protocols, instrumentation and equipment for future space exploration. Guidelines for human-machine interactions and automation requirements will be established; a dexterous EVA glove will be designed using laser mapping technology; and crew selection and support systems, intervention techniques, and coping regimes for stress management will be further developed.

The **Environmental Health Program** will focus on environmental risk assessment by developing a toxicology database and contamination modeling capacity, determination of Spacecraft Maximum Allowable Concentration (SMAC) limits, and developing new technologies for environmental monitoring. The program also will focus on characterizing the spacecraft environment by assessing air quality and the effects of laboratory operations, and by determining the presence of irritant gases.

Research in **radiobiology** requires the continuing development of instrumentation that complements traditional dosimeters and is capable of characterizing energetic charged particles, and on determining optimum shielding and other countermeasures to ameliorate the consequences of radiation exposure.

A key element of space life sciences enabling research is **CELSS**. Near-term CELSS research will emphasize system definition studies for a hybrid physicochemical-biological life support system intended for long-duration space missions. The program will also support critical studies in controlled-environment plant production, food processing and nutrition, and regenerative waste processing.

The **Space Biology Program** will continue to focus on the mechanisms by which calcium ions and calcium mediated physiologic mechanisms are affected by gravity. Biochemical and physiological processes which regulate growth and development in plants and animals will be studied on the ground, under conditions which simulate physiological changes produced in weightlessness, and compared to actual flight experimental results. The program will continue to expand the knowledge of cell division rates, chromosomal integrity patterns of differentiation, and changes in cell shape as they are affected by exposure to weightlessness. Experiments to address these issues will be conducted in the Shuttle mid-deck (small payloads) and in Spacelabs. Additional experiments will be flown on the Soviet biosatellite mission and possibly on the Space Station Mir.

The **Exobiology Program** will, in the near-term, emphasize the development of new flight experiment concepts for future use on planetary exploration missions and to use SSF to investigate models of early solar system evolution. The program will also support research on the mechanisms for the synthesis of biologically significant molecules in space, their incorporation into planetary bodies, and the origin and subsequent evolution of life on Earth.

The **Biospheric Research Program** will continue to support research leading to an understanding of how biological processes interact with planetary processes and how humans affect this interaction. Specifically, ground-based research and models of biogenic gas production in wetlands, temperate forests and tropical forests will provide the baseline necessary to expand to the regional and global level using remote sensing technology. Another area which will receive continued emphasis is the detection and monitoring of disease vectors (specifically the mosquito that carries malaria) using a combination of ground-based and remote sensing techniques.

4. Search for Extraterrestrial Intelligence (SETI)

The SETI Microwave Observing Project is planned to begin operation in October 1992 to coincide with the 500th anniversary of Columbus' arrival in the New World. The primary activity in the project during FY 1992 will be to continue building and testing the system in preparation for initial full systems deployment. The first of the Targeted Search systems will be completed, integrated, and tested in FY 1992. Field testing and later integration into the Arecibo telescope in Puerto Rico will take place. The purchase and assembly of the remaining systems will be started, and planning will be continued for their deployment to observing sites worldwide. Other activities will include the development of operational planning for both the Sky Survey and the Targeted Search.

5. NASA Specialized Centers of Research and Training (NSCORTs)

The initiation of the NSCORT Program and the establishment of the first centers in the latter part of 1990 were highly significant steps in the strengthening of university-based research in space life sciences. In FY 1992, two additional NSCORTs will be established. They will complement the three NSCORTs established in 1990 (in the areas of CELSS, environmental health, and developmental biology), and the two selected in 1991 (in the areas of radiation health and exobiology), leading to the implementation of an NSCORT in each major space life sciences program area.

6. Mission from Planet Earth

Beginning in FY 1992, the space life sciences program will conduct Pre-Phase A and Phase A studies in areas focusing on participation in human and precursor lunar-Mars missions. These areas include artificial gravity, planetary protection, advanced remote medical care, and human factors research. Trade studies of physiological effects of microgravity and engineering options for artificial gravity systems will be a significant component of this activity.

III. IMPLICATIONS OF THE SPACE LIFE SCIENCES STRATEGY

Fiscal year 1989 was a pivotal year in the space life sciences program. The development of the science implementation strategy with community consensus has paved the way for the establishment of a cohesive life sciences program. This program is designed to optimize utilization of resources to achieve formulated goals and objectives. In 1989 we began the Extended Duration Orbiter Medical Project as an enhancement to the Operational Medicine Program. This enhancement was driven by NASA needs to extend the flights of the Space Shuttle. The definition of the Centrifuge Facility Project also began in 1989. In 1990 we provided for an increase to the U.S./U.S.S.R. cooperative efforts in biology and medicine through participation in the Mir program. We also initiated the Phase-B studies for the Centrifuge/Space Biology Initiative and began to ramp up for the SETI Microwave Observing Project. SETI Phase C/D and the NSCORT enhancement to the base R&A got fully underway in 1991. Phase B of the LifeSat platform as part of the RBI was started in 1991. Unfortunately, the base program remained at a level-of-effort and the delays in the Spacelab Life Sciences missions diverted resources to maintain schedule readiness, with no modern flight hardware added for subsequent missions. While the overall program has shown a healthy growth in 1990, major problems remain in the implementation of enabling research needed to support SSF.

The implementation of the present program was made possible by adhering to the following budgetary decision process since 1989:

1. Maintain the core research and development program for:
 - a. near-term approved flight facilities and experiments (those in design and development, Phases C/D);
 - b. research and engineering infrastructure at the NASA field centers through the establishment of program/projects; and
 - c. viable university and industrial base.
This base will be enhanced, as resources permit, by increasing the university participation in space life sciences programs and increasing educational opportunities.
2. Maintain approved ground-based projects (those in design, development, and operations, Phase C/D/E).
3. Maintain definition of the appropriate flight facilities through Phase B.
4. Maintain the necessary advanced planning studies through Phase A and Pre-Phase A.

FY 1992 will be a critical year for the space life sciences program. The requested budget will provide a stable base for the life sciences and allow for a progressive implementation of the research and development program, both ground and flight.

A. BUDGET

Using the guidelines described above, a set of options have been developed which will allow the implementation of previously described strategies. These guidelines provide for the application of a consistent decision process concerning programmatic priorities at the disciplinary level when faced with the realities of the overall federal budget. The commitment of the Administration, the U.S. Congress, and NASA to the implementation of the overarching missions and National Space Policy, while maintaining a viable research and development base, will have a profound impact on the execution and schedules of the space life sciences program. Another major factor in the implementation of the program will be the participation and contributions of other U.S. agencies, such as NIH, NSF, DOE and DOD, and of international partners in the space life sciences.

The budgetary guidelines developed by the space life sciences program are aimed primarily at protecting and preserving the core program from potential impacts and subsequent delays which might occur in other major flight projects and/or overarching initiatives. Thus the core program will continue to accumulate the knowledge base by maintaining and supporting a viable life sciences research and bioengineering community within and outside of NASA. This knowledge base is also essential to the success of NASA in maintaining the life sciences infrastructure when new initiatives and major missions are implemented.

Thus, the preservation of the core program is of highest priority for the successful implementation of the space life sciences program. An option under consideration is to enhance the growth of the life sciences program in FY 1993 commensurate with the overall agency's Space Shuttle missions and Space Station Freedom schedules, thereafter maintaining the core program at an annual growth rate of 15% after inflation.

B. ACCESS TO SPACE

Most of the missions currently being planned utilize the Space Shuttle and Spacelab missions, LifeSat bioplatforms, and SSF. International missions utilizing both U.S. and foreign satellites are an important part of the space life sciences program. The Life Sciences Division also facilitates and integrates flight research sponsored by other U.S. Government agencies. The implementation of this strategy has resulted in the NASA life sciences programs developing flight experiments for unmanned Soviet COSMOS biosatellite missions, Space Shuttle middeck locker capabilities, and a variety of Spacelab missions, both dedicated to life sciences and in concert with other participating U.S. organizations and international partners. The Spacelab missions now enable the performance of experiments that require 7 to 10 days of flight and human intervention on-orbit. A limited range of analytical capability is provided on these missions, with the primary objective being to perform observations and collect samples and specimens during flight for subsequent Earth-based analyses. The extension of Spacelab flights to periods of time beyond 13 days will enable experiment replication on the same flight.

Flights of the free-flying reusable biosatellite (LifeSat) currently in planning stages with its unique technical attributes will greatly expand the capabilities and flexibility available for space life sciences enabling research.

In the near term, the continuing Space Shuttle/Spacelab series of missions and the initial flights of LifeSat will be the most important categories of flight opportunities. It is essential that the extensive life sciences research conducted on Earth be accorded continuing and regular access to flight as a means of collecting unique data, validating scientific concepts and procedures, and verifying countermeasures, while serving as a testbed for future SSF research techniques and equipment.

C. TECHNOLOGY

A strong ongoing program of technology development must be pursued to enable space life sciences activities.

To support the planned research thrusts utilizing Space Shuttles, Spacelabs, Space Station Freedom, and LifeSat, automated monitoring control and analysis capabilities are key. Also of prime importance are centrifuge facilities, animal habitats and supporting equipment, refrigerator-freezers, and sample processing and delivery techniques

and equipment. Ground-based and observatory science needs include, for example, enhanced signal processing and detection systems for SETI, and telescience capabilities.

Technology requirements for current or planned human missions include improved EVA and life support systems, real-time environmental control, radiation monitoring, automated expert systems for medical care, microbial monitoring and decontamination. Mission from Planet Earth presents a significantly greater need for advanced technologies to enable human exploration missions. These include radiation shielding, regenerative life support systems, and automated and expert medical care and delivery systems. Artificial gravity systems may be required for exploration missions; these technologies could take the form of tethered or rigid systems, providing partial or continuous gravity as a countermeasure.

D. INSTITUTIONS

The Life Sciences Division will continue to develop an infrastructure to facilitate the future program growth required to support the major exploration initiatives of the 21st century. The basic structure is in place, and will be enhanced by upgrading NASA field center facilities and capabilities, enriching cooperative programs with other Federal agencies, strengthening ties to the university and industrial communities, and increasing international collaboration.

1. NASA Infrastructure

NASA Headquarters. The Life Sciences Division of the Office of Space Science and Applications is responsible for the overall planning and direction of NASA's space life sciences program. Within the Life Sciences Division, three program branches and an Aerospace Medicine Office are responsible for the scientific, technical and programmatic aspects of the Division's activities. Other staff elements include the Chief Scientist and Strategic Planning and Program Control.

NASA Field Centers. NASA field centers are the source of expertise for program definition, research program implementation, unique ground and flight facilities, and flight mission planning and operation. Center management is represented on the Life Sciences Senior Management Council, which ensures timely communication and working relationships.

The following summarizes the significant life sciences activities and project management responsibilities at NASA field centers:

- Ames Research Center—Project management for: Space Biology Initiative (SBI—non-human research, Gas-Grain Simulator, CELSS Test Facility); Centrifuge Facility Project; Rhesus Facility; Research Animal Holding Facility; science modules for LifeSat biology; COSMOS flights; biological research on Mir; and SETI. Research and development in: biomedical disciplines (with primary emphasis upon basic sciences); human factors; planetary environments, and artificial gravity requirements for future human exploration missions; biospheric research; exobiology; life support, including CELSS technology and flight experiments; advanced high pressure EVA suits.
- Jet Propulsion Laboratory—SETI sky survey, LifeSat science support, and research and analysis in radiation biology.
- Johnson Space Center—Project management for: operational medicine; Space Station Freedom, CHaCS; EDOMP; BMAC; SBI (human research elements); RBI/LifeSat spacecraft development; Cosmic Dust Collection Facility; Spacelab Life Sciences missions; and human research on Mir. Research and development in: biomedical research (with primary emphasis upon clinical and applied sciences and countermeasures); environmental health support for manned missions and space human factors; radiation health, environmental monitoring, and operational life support; advanced high pressure EVA suit; EVA systems requirements and training; and lunar CELSS.
- Marshall Space Flight Center—Research, development, and project management for SSF Environmental Control and Life Support System. Management for Spacelab missions.

- Kennedy Space Center—Project management for the CELSS Breadboard Project and the Space Life Sciences Training Program. Life sciences flight experiment support for both human and nonhuman biological specimens. The Clinical Practice Library of Medicine/Medical Emergency Diagnostic Assistance System. The Life Sciences Flight Experiment Program at KSC.

Advisory System. The Life Sciences advisory infrastructure is an extremely important tool for program assessment and long-range planning; it encompasses both internal and external committees. The Life Sciences Division will continue to receive advice from National Academy of Sciences committees focusing on life sciences disciplines. The NASA internal advisory infrastructure includes two committees—the Aerospace Medicine Advisory Committee (AMAC) in the area of clinical and preclinical medical studies necessary to enable human space flight, and the Space Science and Applications Advisory Committee (SSAAC) and its Life Sciences Advisory Subcommittee (LSAS), primarily in the area of non-medical basic science studies.

2. Universities

The university community continues to offer a broad research and training base for the Life Sciences Division. This diverse community is also the source of the majority of the members of the discipline working groups and advisory elements. The initiation of the NASA Specialized Centers of Research and Training (NSCORT) Program and the establishment of the first centers in the latter part of 1990 are highly significant steps in the strengthening of university-based research in life sciences. As NASA's planning for exploration missions matures and resources become available, university research will assume even greater importance in select areas of research.

3. Other Federal Agencies

Joint activities with other Federal agencies are essential to the continued development of a national space life sciences program base. The Interagency Working Group (IAWG) in biomedical research will continue to enhance joint efforts between NASA and the National Institutes of Health (NIH). Complementary ground-based research programs are being developed in the cardiopulmonary, musculoskeletal, and neuroscience disciplines. Similar cooperative programs are planned with the Departments of Agriculture, Energy, and Defense, and the National Science Foundation. Relationships with other agencies are also being developed. These joint activities will ensure that ground-based and flight facilities, with the appropriate management and scientific infrastructure, are available to support the needs and interests of other agencies as well as those of NASA in the utilization of space as a scientific tool. The Life Sciences Division will coordinate across the spectrum of organizations interested in space life sciences research. Specific interests will be integrated to ensure the development and execution of ground and flight research programs that meet the needs of all participants.

4. Ground-Based Facilities

A significant portion of NASA space life sciences research is conducted in ground-based laboratories. These investigations are conducted for the purposes of validating space-flight data; simulating conditions that might occur in space flight; developing analog models for weightlessness; and verifying new hypotheses prior to the execution of flight experiments. Over the last 15 years unique ground-based facilities were developed at NASA field centers and universities. The following represents a partial list of such facilities:

- Ames Research Center: Bedrest facility, human and animal-rated centrifuges, flight simulators, variable gravity research facility, biological research laboratories, crop growth research chambers, and research animal colonies.
- Johnson Space Center: Flight simulators, SSF health maintenance training facility, clinical research laboratory facilities, proportional radiation counter facility, flight baseline data collection facility, hypo- and hyperbaric human-rated facilities, water immersion training facility, human factors facility, life support test chambers, toxicology facility, and Spacelab Life Sciences and CHeCS training facilities.
- Kennedy Space Center: Preflight baseline data collection facility and CELSS breadboard facility.
- Universities: Slow rotating room at Brandeis University.

E. INTERNATIONAL COOPERATION

The Life Sciences Division is continuing to pursue a vigorous international program involving the major space agencies of the world, especially in the training of life scientists. The goal of international cooperation in the space life sciences is to increase the overall worldwide science return from space life sciences research. Coordinated activities are underway with Canada (CSA), the European Space Agency (ESA), the Federal Republic of Germany (DARA), France (CNES), Japan (NASDA), and the U.S.S.R. In addition, discussions have been held and will continue with several other countries to determine the feasibility of establishing formal collaborative relationships.

An International Life Sciences Strategic Planning Working Group was established in 1990. The Life Sciences Division is participating with international partners in the planning and development of Spacelab International Microgravity Laboratory (IML) missions. SL-J is a Japanese Spacelab mission and the SL-D is a series of dedicated German Spacelab missions in which NASA Life Sciences participates. France, through CNES, is participating in the development of the Rhesus Facility, which will be flown on the Spacelab Life Sciences 3 mission. Five partners—France, Europe, Japan, Germany, and Canada—are actively planning for science experiments to be flown on LifeSat missions. Mechanisms for joint experiments and sharing of data from U.S. and U.S.S.R. manned and unmanned missions have been established. In planning for the utilization of SSF for life sciences research, international partners intend to provide complementary inflight facilities, and joint studies will be conducted.

APPENDIX I: SPACE LIFE SCIENCES PROGRAMS — INDIVIDUAL STRATEGIES

Life Support Programs

- Space Physiology and Countermeasures**
- Radiation Health**
- Environmental Health**
- Space Human Factors**
- Controlled Ecological Life Support Systems**

Research Programs

- Space Biology**
- Biospheric Research**
- Exobiology**

Operational Medicine Program

LIFE SUPPORT SPACE PHYSIOLOGY AND COUNTERMEASURES

PROGRAM GOALS

The Space Physiology and Countermeasures Program has two goals:

- Understand the underlying mechanisms of the physiological changes that occur during space flight, and
- Develop and validate countermeasures and technologies to optimize crew safety, well-being, and performance inflight and on return to Earth.

VISION

By the end of the century, as a result of our programs of flight and ground-based research, we will have achieved significant progress in understanding the mechanisms underlying physiological adaptation to space flight and in developing countermeasures to the undesirable effects of spaceflight on crewmembers.

We will emphasize application of space physiology research and technology to disease and other health problems on Earth.

LEVEL I SCIENCE REQUIREMENTS

Develop systems and procedures to maintain crew health and performance sufficient to accomplish mission objectives. This will include the following:

- Cardiopulmonary Physiology - Understand mechanisms of changes in cardiovascular function with space flight and develop countermeasures using real and simulated weightlessness in humans and animals.
- Musculoskeletal Physiology - Understand mechanisms, determine health consequences, and develop countermeasures to muscle atrophy and bone demineralization using real and simulated weightlessness. Develop exercise equipment and procedures for maintaining bone integrity and muscle strength.
- Neuroscience - Understand vestibular and sensory adaptation, central nervous system processing, and neuro-motor control in weightlessness and develop countermeasures where appropriate, including effective countermeasures to space motion sickness.
- Regulatory Physiology - Understand integrative mechanisms regulating responses to space flight, including those related to circadian rhythms, fluid and electrolyte balance, endocrinology, pharmacodynamics, metabolism and nutrition, immunology, hematology, and temperature regulation, and develop requirements and countermeasures where necessary, including nutritional requirements for long-duration missions.

THE STRATEGY

Research in Space Physiology and Countermeasures to accomplish these objectives over the next decade will build on the existing science knowledge base and will consist of a combination of integrated ground-based and flight research.

- Animal models will be important in investigating basic mechanisms of physiological adaptation.

- Human subjects, including crewmember volunteers for Spacelab and other Space Shuttle missions and volunteer subjects for ground-based research using simulations of space flight, will be important in investigating applied research issues.

Collaborative efforts with our international partners will include continued cooperation with the Soviets to share equipment and data in their Mir Program and to fly experiments on the Cosmos biosatellite; collaboration with the French and German Space Agencies on flight and ground research; cooperation with the Japanese and European Space Agencies on Spacelabs and Space Station Freedom; and cooperation with the Canadians on Spacelabs.

NEW INITIATIVES

- **Neurolab (Spacelab)**
In connection with the U.S. Interagency Program "Maximizing Human Potential - Decade of the Brain 1990-2000," NASA will have a Spacelab dedicated to brain and behavior, in which state-of-the-art neurosciences research will be conducted.
- **NSCORT Program in Integrative Physiology.**

LIFE SUPPORT RADIATION HEALTH

PROGRAM GOAL

The overall goal of the Radiation Health Program is to establish the scientific basis for the radiation protection of humans engaged in the exploration of space, with particular emphasis on lunar and Mars missions.

VISION

By the end of this century the Radiation Health Program will have enabled us to predict the probabilities, in excess of natural incidence, of deleterious health effects, including carcinogenic effects due to radiation exposure.

LEVEL I SCIENCE REQUIREMENTS

SHUTTLE:

- Monitor radiation exposures to crews.

SPACE STATION FREEDOM:

- Monitor radiation exposures to crews to assure that guidelines for radiation exposure limits are being met.

SPACE EXPLORATION INITIATIVE:

- Determine health risks from GCR and develop appropriate exposure limits.
- Determine health risks for exposures to solar energetic particles and develop warning and shielding requirements for solar particle events.

THE STRATEGY

The strategy to meet the science requirements consists of a ground-based research program to develop the scientific basis for radiation protection in space, complemented by a space-based program to validate the scientific results in the space radiation environments and inside the spacecraft and other structures. Some of the studies required to meet these requirements are properly performed by other components of NASA, other Federal agencies, Federally supported research laboratories, universities and foreign institutions.

The ground-based research program will be executed at one or more accelerator facilities, which provide beams of protons and heavier charged particles to simulate the space radiation environment. Reference beam species and beam energies will be used to integrate experiments and enable intercomparison of their results. The biological research program focuses on molecular and biological studies to elucidate the mechanisms of cellular responses to radiation, and on tissue and organ studies to elucidate the cellular response, with particular reference to life-shortening effects, mainly cancer.

The space-based program is centered on the use of LifeSat, a reusable, free-flying satellite with a unique set of capabilities. Multiparameter studies on LifeSat will test sensitive aspects of the predictive models that require improvement. Some of the predictions that will be tested with statistically significant results include the relative abundance of different particles and their flux behind different thicknesses of test materials, transformation of human cells in culture, differential genetic responses to radiation of different ionization density in small organisms, and effects of radiation and weightlessness on the development of microorganisms and plant seeds. The outcome of the comparison of ground-based prediction with space-based experiment is a measurement of the uncertainty associated with the prediction of radiation effects in space. This is the most important product of the research program.

NEW INITIATIVES

- Radiation Biology Initiative. This will develop and operate facilities on the ground (either the Lawrence Berkeley Laboratory or the Brookhaven National Laboratory) and in space (LifeSat) for heavy ion radiobiology.
- NSCORT Program in Radiation Health.

LIFE SUPPORT ENVIRONMENTAL HEALTH

PROGRAM GOALS

The Environmental Health Program, which comprises microbiology, toxicology, and barophysiology, has three goals:

- Utilize ground-based studies to understand the effects of the spacecraft and EVA environments on humans.
- Specify, measure, and control these environments.
- Develop countermeasures where necessary to optimize crewmembers' health, safety, and productivity.

VISION

The Environmental Health Program by the end of the century will produce an understanding of the environmental hazards within and outside of spacecraft and will have developed effective monitoring and countermeasures to assure the safety of crewmembers on long-duration missions. Applications for humans on Earth will be emphasized.

LEVEL I SCIENCE REQUIREMENTS

1. Define microbiological and toxicological standards and develop advanced environmental monitoring technology.
2. Understand the biochemical and biophysical effects of variations in component parts of the man-made atmosphere in space environments to allow selection and maintenance of safe and efficient gaseous environments in different situations and in different eras of the space program.
3. Determine whether a prolonged stay in microgravity would induce sufficient physiological and biochemical changes to render crewmembers more susceptible to toxic chemicals.
4. Establish acceptable and appropriate ranges of gas composition, pressure, temperature, and humidity for all current and future missions.
5. Determine the interactive effects of all potential atmospheric components and factors on physical and psychological well-being and crew performance.
6. Determine the effect of microgravity on the microbial cell, its growth, metabolism, pathogenic potential, virulence factors, and sensitivity to antibiotics and disinfectants.
7. Establish criteria for the number of microbial organisms in a defined volume of air and water that could be considered realistic and safe.
8. Define safe protocols for training and define decompression models to predict assessment of the incidence of decompression sickness.

THE STRATEGY

Research in Environmental Health to accomplish these goals will build on existing science and operational knowledge bases and will involve an integrated ground and flight research effort. The Neutral Buoyancy Laboratory (NBL) and chamber tests simulating EVA decompression will be used to define safe protocols for training and decompression, expand the data base, and develop models.

Routine monitoring of Space Shuttle flights for selected toxicological contaminants and research on microbial contamination and growth will be conducted.

The Environmental Health NSCORT at the University of Rochester will be synergistic with other aspects of the Environmental Health Program and will identify hazardous situations, develop detection systems, and use data to develop computer models to estimate growth and flow of contaminants.

NEW INITIATIVES

Ecolab Spacelab. A Spacelab dedicated to all aspects of the spacecraft environment, including environmental health issues, will be investigated.

LIFE SUPPORT SPACE HUMAN FACTORS

PROGRAM GOALS

The goals of the Space Human Factors Program are to:

- Understand the psychological, behavioral, and performance responses to space flight.
- Develop design requirements, protocols, and countermeasures to enable safe, productive, and enhanced crew performance.

VISION

By the end of the century, through a combination of flight and ground-based research, the Space Human Factors Program will have made significant progress in understanding crew needs and developing systems in the areas of crew support, small-group interactions, mission work analysis, workload assessment and performance, selection and training, habitability, human-machine systems and automation.

LEVEL I SCIENCE REQUIREMENTS

It is important to develop the knowledge base required to understand the basic mechanisms underlying behavioral adaptation to space flight and the capabilities and limitations of the crewmember in the unique environments that will be encountered during future space missions. This will include:

- Understand behavioral processes and performance capabilities in space.
- Develop habitability requirements for extended-duration missions.
- Develop guidelines for human-machine interactions for extended-duration missions.
- Develop crew support systems for extended-duration missions.
- Develop selection and training protocols for extended-duration missions.
- Develop principles and requirements for crew organization, leadership, and composition for extended-duration missions.
- Develop human performance requirements for operations and procedures for space missions.
- Develop a glove to allow dexterity in EVA.

THE STRATEGY

To fulfill these science requirements, the Space Human Factors Program will build upon the existing knowledge base, which is an extensive and comprehensive core of ground-based and aviation-based research and technology. The ground-based program will use analogs, mock-ups, laboratory studies, modeling and simulations to study psychosocial factors important to crew health, well-being, and performance.

Human performance experiments are planned for the International Microgravity Laboratory 2 (IML-2) scheduled for flight in 1994.

In addition, interagency cooperation will be developed within the program. The Space Human Factors Program will work with the U.S. Air Force in the areas of crew workload and mission analysis; with the National Oceanographic and Atmospheric Administration (NOAA) to use the undersea habitat as an analog for studying effects of confinement on psychological health and group dynamics; and with the National Science Foundation (NSF) to develop the Arctic and Antarctic as analogs for space exploration.

International collaborative projects include the Rhesus Research Facility currently being developed by NASA and the French Space Agency Centre Nationale d'Etudes Spatiales (CNES) to study behavioral processes in microgravity. Similar studies will be conducted in conjunction with the Soviets during joint activities on Cosmos biosatellites, and crew selection studies are planned on the Mir space station. The Space Human Factors Program plans collaboration with the German Space Agency (DARA), and is negotiating with the European Space Agency (ESA) on potential joint participation in isolation studies.

NEW INITIATIVES

Initiatives being proposed within the Space Human Factors Program during the next 5 years include:

- The Human Factors Analog Initiative. Initiative to utilize isolated, confined and potentially hazardous analogs to study selected space physiology issues in the polar regions (Antarctic and Arctic) and in undersea habitats.
- NSCORT Program in Human Factors.

LIFE SUPPORT CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEMS (CELSS)

PROGRAM GOAL

The goal of the CELSS Program is to develop regenerative life support systems by combining biological and physical/chemical processes capable of producing and recycling the food, air, and water needed to support long-term human missions in space in a safe and reliable manner.

VISION

We will design, develop, and test a ground-based human-rated CELSS and simultaneously initiate a space-based experiment program to identify and resolve issues related to the behavior and operation of CELSS biological and non-biological subsystems by flight experimentation in micro- and fractional-gravity. Ultimately, a human-rated, space-based CELSS will provide enabling life-support capabilities for long-duration missions.

LEVEL I SCIENCE REQUIREMENTS

To guide the research and technology development needed, three supporting research goals have been established:

1. Understand how life can be maintained in stable, autonomous systems.
2. Acquire the knowledge needed to make life support systems for long-duration missions independent of resupply.
3. Develop the technology base needed to build autonomous life support systems.

THE STRATEGY

The approach to the development of the CELSS will be to emulate the fundamental mechanisms by which life is sustained on Earth. Three essential terrestrial ecological processes are photosynthesis, respiration, and microbial mineralization. However, because of the constraints imposed by space missions, i.e. limited volume, mass, energy, and human resources, CELSS will need to substitute physical/chemical and computational processes or devices for the natural biological and geological feedback mechanisms that operate on Earth. The overall goal will be to develop systems that will provide life support consumables in an effective, efficient, safe, and reliable manner within anticipated mission constraints.

To carry this out, the following strategy will be followed:

1. Subsystem Development

Carry out small-scale laboratory-based research and technology development on individual biological and non-biological systems and processes of the CELSS to select the best candidate subsystems for inclusion in CELSS systems.

2. System Studies

Develop increasingly sophisticated CELSS prototype systems that display sequentially greater size, degree of integration, and level of complexity. These facilities will include small-scale integrated subsystems, and progress to breadboard systems, ground-based human-rated testbeds, and eventually evolve in engineering prototypes of space CELSS for a specific mission application. Conceptual and mathematical modelling studies will be included in these system studies.

3. Flight Studies

Perform flight experiments that test the effect of the total space environment on CELSS design features and processes (including physical/chemical and biological). This will include gravity, radiation sensitivity, and other parameters of the space environment.

This strategy will be implemented by maintaining close collaboration and cooperation with relevant offices both within and outside of NASA. The CELSS program will benefit from the expertise offered by such NASA programs as the Space Biology Program of the Life Sciences Division, the Advanced Life Support Program of the Office of Exploration and Space Technology, and the ECLSS Program of the Space Station Freedom Program Office. Outside NASA, the U.S. Department of Agriculture, the U.S. Department of Energy, and the National Science Foundation will provide needed information of basic and applied plant and crop research. The industrial and commercial sectors may also be involved in research concerning various aspects of the CELSS program.

4. NSCORT

The major focus of the NASA Specialized Center of Research and Training (NSCORT) at Purdue University is the parallel development of food production, food processing, and waste management for a space-operated controlled ecological life support system (CELSS). An interdisciplinary group with expertise that ranges from systems engineering to biotechnology will (1) apply recombinant DNA techniques to appropriately modify photosynthetic microorganisms and crop plants for the food, atmospheric, and energy requirements of a CELSS; (2) specify human nutritional requirements under long-duration missions and for colonization under a hypogravity environment; and (3) model the overall life support system in order to integrate all important subsystems of a functioning CELSS. The overall research effort will be complemented by an extensive training component that will include postdocs, graduate students, and undergraduates.

NEW INITIATIVES

Human-rated facilities for CELSS development.

RESEARCH PROGRAMS SPACE BIOLOGY

PROGRAM GOALS

To use the microgravity environment as a tool to advance knowledge in biological science, and to understand the role of gravity in biological processes and how different species are affected by and adapt to a microgravity environment.

VISION

We will begin to achieve a scientific understanding of the effects of gravity on plants and animals, at the most fundamental levels, and will provide basic knowledge of biological processes through experimentation in the microgravity environment of space.

LEVEL 1 SCIENCE REQUIREMENTS

1. Understand the basic mechanisms whereby plants perceive, transduce, and respond to gravity; identify and study the role of gravity and microgravity on developmental, reproductive, metabolic, and transport processes in plants.
2. Identify how single cells sense gravity, including both direct and indirect environmentally mediated effects, how this information is transduced, and how cells respond to alterations in gravity.
3. Determine the effects of gravity on developmental processes in plants; establish whether developmental cycles (from egg-to-egg) will occur unaltered over multiple generations in space.
4. Understand how the brain processes information by ascertaining the organization and functioning of the gravity-sensing endorgans of the mammalian inner ear; and elucidate the stages by which the gravity-sensing system evolved.
5. Identify how gravity influences the type, pattern, and amount of biomineralization and muscle in structural biosystems; understand interactions between gravity and internal and external factors on structural biosystems; and specify the time course of musculoskeletal adaptation and readaptation to altered gravity.
6. Understand the role of gravity on animal regulatory mechanisms: the generation and/or entrainment of circadian rhythms, the internal synchronization of several circadian functions, and one or more selected homeostatically controlled systems.

THE STRATEGY

- Expand support of ground-based approaches that permit utilization of modern research techniques and instrumentation to target analyses at the most fundamental levels; confirm fidelity of ground-based models.
- Continue to develop a vigorous flight experiments program using the range of flight opportunities to permit identification, confirmation, and understanding of effects due to microgravity. Repetition of experiments to generate a scientifically valid data set is essential.
- Utilize generic flight hardware developed and shared by this nation and others and that are capable of evolving over time; utilize inflight centrifuges.

- Develop a state-of-the-art inhouse plant physiology laboratory at Kennedy Space Center to conduct research complementary to that of university laboratories and to act as a resource to facilitate flight experiment preparation and execution in plant biology.
- Expand cooperative efforts with other NASA programs, international collaborators, and other government agencies to maximize utilization of resources and information exchange.

NEW INITIATIVES

A Gravitational Biology community revitalization initiative is in the planning stages. The plan is to enhance and broaden the current program across the scientific disciplines of plant, cell and developmental, biomineralization, musculoskeletal, and regulatory biology, addressing the science requirements through the strategies outlined above. When Space Station becomes available, research can be conducted in either the manned or unmanned mode. Dedicated space biology research will also be conducted on LifeSat.

RESEARCH PROGRAMS BIOSPHERIC RESEARCH

PROGRAM GOAL

To utilize ground and space-based studies to understand how biological processes and planetary properties affect one another, and how human activities affect this interaction

VISION

We will obtain a predictive understanding of the mechanisms by which the terrestrial biosphere interacts with the planet, how anthropogenic activities can perturb these interactions, and will define strategies by which these perturbations can be moderated or mitigated.

LEVEL I SCIENCE REQUIREMENTS

1. Establish a basis for assessing the major pathways and rates of exchange for carbon, nitrogen, sulfur, and phosphorus moving into and out of terrestrial and aquatic ecosystems.
2. Establish a basis for extrapolating local rates of biological activities to biospheric rates and effects, with particular attention on the role of gases and their oxidation products.
3. Develop mathematical models that represent the dynamics of the global cycles of carbon, nitrogen, sulfur, and phosphorus, including their interactions and the key processes that control their dynamics.
4. Study mechanism of population and community ecology as underlying biogeochemical processes.
5. Apply these insights and technologies to issues of global human health and welfare.

THE STRATEGY

- Continue and extend support for the present program in biogeochemical cycling
- Support new emphasis on research at the population and community level using remote sensing as a major tool
- Apply knowledge to the development and validation of predictive models of biospheric/planetary interactions
- Apply predictive abilities to issues of human health and welfare
- Promote development of remote sensing expertise in the ecological science

NEW INITIATIVES

The Biospheric Program is planning a Research and Analysis augmentation consisting of two elements: *Terra*, and *The Fresh Water Initiative*.

Terra is a multi-year initiative that will extend and broaden the current Program. Scientific themes will include globally important biogeochemical cycles, population and community dynamics that impact planetary processes, and global change as it impacts, and is impacted by, ecosystems.

The Fresh Water Initiative is a multi-year interagency program devoted to acquiring a predictive understanding of freshwater systems in the context of global change. Study areas will include freshwater ecology, hydrology and water resources. The Initiative will coordinate ongoing and future programs in fresh water systems to:

- Improve detection, assessment and prediction of environmental effects upon these systems, and
- Develop management and mitigation alternatives for potential global change scenarios.

RESEARCH PROGRAMS EXO BIOLOGY

PROGRAM GOAL

The goal of NASA's Exobiology program is to understand the origin, evolution, and distribution of life in the universe. The attainment of this goal is being sought by concentrating on specific research objectives that trace the pathways taken by the biogenic elements, leading from the origin of the universe through the major epochs in the evolution of living systems and their precursors. These epochs are 1) The cosmic evolution of the biogenic compounds, 2) prebiotic evolution, 3) the early evolution of life, and 4) the evolution of advanced life.

VISION

The Exobiology program conducts research as part of the Life Sciences Division program, and interacts with programs elsewhere within NASA in an integrated effort to accomplish the goal of understanding life in the universe. Exobiology investigations formed an integral part of the science objectives of the Solar System Exploration Division, and also formed a major portion of the National Academy of Sciences recommendations for research in Astronomy and Astrophysics. Accordingly, advanced planning within the Exobiology program encompasses joint activities with both the Solar System Exploration Division and the Astrophysics Division within OSSA. Future plans include research activities conducted on the ground, aboard robotic planetary spacecraft and Earth-orbiting telescopes, on the Space Shuttle and on Space Station Freedom, and eventually research conducted by humans on or from the Moon and Mars.

LEVEL I SCIENCE REQUIREMENTS

1. Determine the history of the biogenic elements (C, H, N, O, P, S) from their birth in stars to their incorporation into planetary bodies.
2. Understand the pathways and processes leading from the origin of a planet to the origin of life. Research strategies in this area investigate the planetary and molecular processes that set the physical and chemical conditions within which chemical evolution occurred and living systems arose.
3. Determine the nature of the most primitive organisms, the environment in which they evolved, and the way in which they influenced that environment by investigating two natural repositories of evolutionary history available on Earth and perhaps elsewhere: the molecular record in living organisms and the geological record in rocks.
4. Determine the extrinsic factors influencing the development of advanced life and its potential distribution, including an evaluation of the influence of extraterrestrial influences and planetary processes on the appearance and evolution of multicellular life.

THE STRATEGY

- Maintain a broad program of investigations of the origin, evolution, and distribution of life on Earth over the course of Earth's history, in order to understand the context of life in the universe.
- Prepare exobiologists to make the maximum use of NASA and foreign flight opportunities to extend the range and quantity of space measurements appropriate to exobiology.
- Develop a suite of exobiology capabilities and instruments for inclusion on future planetary missions to the inner and outer planets, and to the small bodies of the solar system.
- Use Space Station Freedom as a platform to conduct fundamental experiments to characterize the role of the biogenic elements and compounds in the origin and evolution of the solar system and its constituents.

- Prepare for the scientific exploration of the Moon and Mars by a combined program of analog studies, instrument development, and robotic and human exploration.
- Conduct observational exobiology using all available platforms to study the formation of life in the universe, and to search for signs of extraterrestrial life.

NEW INITIATIVES

The Program is preparing for the observational phase of the SETI Microwave Observing Project (1992), the Mars Observer mission (1992), the USSR Mars '94 mission (1994), the arrival of the Galileo mission at Jupiter and the launch of the CRAF and Cassini missions to a comet and the Saturn system, and the installation of the Gas-Grain Simulator on Space Station Freedom. Steps are also being taken to prepare for future Space Exploration Initiative missions to Mars and later the Moon. One early step will be the initiation of joint research with the National Science Foundation (NSF) in Antarctica in the 1992-93 season. Follow-on activities in SETI and solar system exploration are planned for initiation early in the first decade of the 21st century.

OPERATIONAL MEDICINE

PROGRAM GOALS

The goals of the Operational Medicine Program are as follows:

- Provide medical support to all manned missions,
- Develop an estimate of medical risks associated with advanced missions with humans,
- Establish biomedical countermeasures and life support research priorities.

VISION

Two primary missions will shape operational medicine activities in the coming decade. The Shuttle Program, under the sponsorship of the Extended Duration Orbiter Program, will fly progressively longer missions during the first half of the 1990s. The EDO Medical Program (EDOMP) is tasked with supporting missions up to 16 days, while assuring the safety of the environment and the capability of crewmembers to function effectively during re-entry, landing, and land contingencies. The key challenge facing the EDOMP is to develop (and validate) effective countermeasures, and to routinely support missions of 13-16 days. To accomplish this task, it will be mandatory to acquire the medical/physiological knowledge to understand the mechanisms of deconditioning on missions of this duration. The ultimate objective is to develop the ability to predict a given crewmembers response to re-entry stresses by doing on-orbit evaluations.

Space Station Freedom (SSF) embodies the U.S. commitment to a permanent presence in low-Earth orbit. The principal aeromedical challenge embodied in the SSF program is the progressive extension of crew stay times in microgravity. Experience to date in both the U.S. and Soviet space programs has resulted in the identification and initial characterization of the human response to long-duration space flight. While many of these responses are adaptive in nature, certain adaptations are maladaptive and may result in medical illness (either inflight or postflight), or impair a crewmember's ability to perform critical mission tasks. These processes must be understood well enough to develop predictive models and methods for on-orbit assessment of deconditioning trends. The programs required to accomplish these objectives will entail a high degree of synergy with other ground-and flight-based research programs, both of an applied and a basic nature. The changing nature of the space program also results in two additional challenges - first, the need to better characterize the medical risks of routine, repetitive EVA, and second, a need to provide quality medical care to crews in an Earth-remote location. A well-designed medical care capability has a role in both preventing morbidity and mortality, and in keeping minor medical problems from progressing to the extent that they result in mission replanning or a medical abort.

In the latter half of this decade, the Operational Medicine Program will dedicate increasing resources to advanced medical concepts for exploration missions. Specific elements will include: 1) requirements definition for third generation medical care systems (including computer-aided diagnostic and telemedicine support), 2) development of crew selection and medical standards, and 3) development of procedures and protocols for health care delivery during long-duration missions. This latter task will require an understanding of the medical consequences of illness/injury states in the space-adapted individual.

LEVEL 1 MEDICAL REQUIREMENTS

1. Understand the medical consequences of spaceflight deconditioning and their operational implications.
2. Characterize the operational medical risks of the proposed missions, including the physiological risks of repetitive EVAs, and the potential medical risks associated with the Shuttle EDO and SSF environment.

3. Develop an understanding of the efficacy of currently employed medical countermeasures and establish biomedical research priorities.
4. Develop the requisite understanding of medical physiology in the space-adapted and/or ill injured crewmember in order to allow medical care in space, which is based on that underlying knowledge.
5. Development of advanced medical care systems and telemedicine concepts to deliver quality medical care in space, within the context of programmatic constraints.

THE STRATEGY

The strategy for meeting these objectives is as follows:

- Develop an understanding of the mechanisms of spaceflight deconditioning by implementing a preventive medicine program, which will limit the progression of those effects. This will be accomplished by direct inflight crew monitoring (such as in the EDOMP and BMAC programs), or by an active interface with the applied life sciences research programs (such as Spacelabs SLS-1, 2, & 3).
- Implementation of the preventive medicine program by means of ground-based medical care and an inflight element which includes routine clinical examinations and prescribed countermeasures to prevent illness/debility due to spaceflight deconditioning. This function is represented programmatically within the Crew Health Care System (CHeCS.)
- Monitoring of spacecraft air, water, and cabin surfaces are an important element of the preventive medicine program. This activity (for SSF) will be implemented by a subsystem (the Environmental Health System, or EHS) of CHeCS.

PLANNED INITIATIVES

Develop a program of clinical investigations into the effects of space flight adaptive mechanisms on the health status of sick or injured crewmembers, and methods for delivering medical care.

APPENDIX II: REFERENCE DOCUMENTS

1. 1979 - *Life Beyond the Earth's Environment: The Biology of Living Organisms in Space* (The Bricker Report), Space Science Board, National Research Council
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3. 1988 - *Earth System Science: A Closer View* (The Bretherton Report), Earth System Sciences Committee, NASA Advisory Council
4. 1987 - *Space Technology to Meet Future Needs* (The Shea Report), Committee on Advanced Space Technology, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, National Research Council
5. 1987 - *A Strategy for Space Biology and Medical Science for the 1980's and 1990's* (The Goldberg Report), Committee on Space Biology and Medicine, Space Science Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council
6. 1988 - *Space Science in the Twenty-First Century: Imperatives for the Decades 1995 to 2015, Life Sciences* (The Swisher/Usher Report), Task Group on Life Sciences, Space Science Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council
7. 1988 - *Exploring the Living Universe: A Strategy for Space Life Sciences* (The Robbins Report), Life Sciences Strategic Planning Study Committee, NASA Advisory Council
8. 1986 - *Remote Sensing of the Biosphere* (The Botkin Report), Space Sciences Board, National Research Council
9. 1986 - *Global Change in the Geosphere-Biosphere: Initial Priorities for an IGBP*, National Research Council, National Academy of Sciences.
10. 1990 - *The Search for Life's Origins: Progress and Future Directions in Planetary Biology and Chemical Evolution*, Committee on Planetary Biology and Chemical Evolution, Commission on Physical Sciences, Mathematics, and Applications, National Research Council